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ABSTRACTS OF PAPERS PRESENTED

Radio Measurements of the Total Solar Eclipse of October 2, 1959 at AFCRC, Hamilton, Massachusetts. JULES AARONS, JOHN CASTELLI, WILLIAM KIDD, AND RONALD STRAKA, *Air Force Cambridge Research Center, Bedford Massachusetts.*—During the recent eclipse of October 2, 1959, measurements of solar radiation were made simultaneously at 1300 and 224 Mc using the 84-ft antenna at Sagamore Hill, Hamilton, Massachusetts, and at 3000 Mc using an 8-ft antenna at the same location. Although the altitude of the sun was low at totality (1°), the center of the sun's disk was tracked quite accurately since refraction corrections based on average refraction values acquired from sunrise measurements of the previous week to 10 days were applied to the antenna pointing. Comparison solar temperatures on the eclipse day and throughout the eclipse, with days both before and after the eclipse were likewise made. At totality, at 1300 Mc, 19% of the average solar energy normal for this elevation was recorded. This figure was about 35% at 224 Mc, and between 14 and 15% at 3000 Mc. These levels appear to be considerably greater than those for low-sunspot-year eclipse measurements reported by other investigators. The higher percentages are probably due to the existence of regions of high intensity at the limbs as evidenced by interferometric maps of the sun at 3000 Mc. After totality at 3000 Mc, the solar records did not increase smoothly, but rather the trace evidenced some roughness as would be expected from the uncovering of a nonuniform sun. Scintillations produced by sources on the sun were observed at 1300 and 3000 Mc. Some measure of the source brightness to disk temperature ratio can be arrived at by observing the scintillations occurring during the first 5° of elevation. At 224 Mc the sun does not scintillate. At 1300 and 3000 Mc, large to violent scintillations were seen when most of the disk was covered. Smaller scintillations were observed even at totality when all but limb source activity was eclipsed.

Faraday Dispersion in the Solar Atmosphere. K. AKABANE AND M. H. COHEN, *Cornell University.*—The degree of linear polarization in solar bursts was measured simultaneously at two bandwidths, 10 and 22 Kc, each having the same center frequency, 201.6 Mc. A number of partially linearly polarized type III bursts were seen, and in every case the burst was more polarized in the narrow band than in the wide band. According to the theory of Faraday dispersion, the ratio between the degrees of polarization observed at two bandwidths gives the degree of polarization at the source ρ_0 , the Faraday rotation angle ϕ , and the dispersion angle θ . A typical example is as follows: $\rho_0 \approx 0.2$; $\phi \approx 5 \times 10^3$ rad, corresponding to $fNHdz \approx 8.5 \times 10^{15}$ (cm, gauss); $\theta \approx 1$ rad for 10-Kc bandwidth. From 37 linearly polarized bursts the following interpretations are tentatively suggested: (1) The intensity of the general magnetic field of the sun can be estimated to be less than 1 gauss at the pole, assuming that the

source of the general magnetic field produces a bipolar field in the equatorial region, as well as in the polar region. (2) In some cases there is a weak magnetic field (~ 1 gauss) near the source of a burst (for the assumed electron density); if a strong magnetic field exists there, it might be disordered so as to diminish the total amount of Faraday rotation. (3) The number of observed bursts increases steeply with decreasing ρ_0 . In the discussion of Faraday dispersion the band shape of the receiver is approximated by a Gaussian function. This results in single-valued determinations of ρ_0 , ϕ , and θ .

Primordial Chemical Composition of the Solar System. LAWRENCE H. ALLER, *The Observatory, University of Michigan.*—The point of view is adopted that the atmosphere of the sun represents closely the original composition of the solar system except for constituents such as deuterium, lithium, boron, and beryllium that are destroyed by thermonuclear reactions deep in the convection zone. The difficulty in obtaining a definitive table of abundances lies in the circumstance that the lines of many elements, particularly the heavy ones, are either masked by lines of more abundant elements or fall in the inaccessible ultraviolet. For some atoms and ions the term analyses are incomplete so partition functions cannot be computed or the f -values are unreliable. Hence a table based on solar abundances only would contain many gaps. The chondritic meteorites probably supply the most reliable abundance data for many elements, although certain metals such as lead and indium appear to be deficient. Accordingly, the best meteoritic data are combined with solar data (Goldberg, Müller, and Aller) and stellar data (from various authors) to obtain a tabulation of abundances. The procedure is very similar to that employed by Suess and Urey except that more stress is laid on the astronomical data. The abundance of iron with respect to other metals of the ferrous group is reduced. The general run of the abundances is very similar to that proposed by Suess and Urey, but certain marked discordances with the tabulation by Cameron are found. Some proposals for further improvements in the data are mentioned.

Interstellar Polarization in the Local Spiral Arm. ALFRED BEHR (introduced by D. Nelson Limber), *Yerkes Observatory and Universitäts-Sternwarte Göttingen.*—By using a differential method, the polarization of 550 stars most of them nearer than 250 pc has been measured with the 34-cm astrophotograph of the Hainberg Observatory in Göttingen. The mean error of a given polarization is $\pm 0^m00005$. A discussion of the results on the basis of the theory of Davis and Greenstein leads to the following results: In distances of up to 25 pc the amount of polarization is found to be smaller than or of the order of the mean error of observation. A statistical discussion however, shows the existence of interstellar polarization even in those distances.

In the case that the magnetic lines of force are perpendicular to the line of sight, we find the relation between polarization and distance

$$p/r = 0^m.000045 \text{ pc}^{-1},$$

and with Hiltner's maximum value of $p/A_v = 0.065$, the amount of interstellar extinction A_v within 25 pc around the sun is estimated to be

$$A_v/r = 0^m.0008 \text{ pc}^{-1}.$$

Observations at distances between 25 and 250 pc generally show an increase of the density of the polarizing matter, the influence of the Taurus and Ophiuchus clouds being evident. Though the scattering of the planes of vibration as well as the scattering in the amount of polarization are high, a preferential alignment of the planes of vibration parallel to the local spiral arm can be observed. The most probable value for the galactic longitude of the vertex of the spiral arm is

$$l = 30^\circ \pm 5^\circ.$$

A polarizing cloud in high galactic latitude has been found in Boötes. The density of polarizing matter is at least five times as high as in the neighborhood of the sun within 25 pc. This cloud also can be found in the results of the measurements of the 21-cm line emission of neutral hydrogen by Erickson, Helfer, and Tatel.

Mass and Mass Distribution in the Andromeda Nebula and the Galaxy. JOHN C. BRANDT, *Yerkes Observatory*.—The theory for the analysis of galactic rotation curves to determine the mass distribution has been developed for the special case of a highly flattened system. This is done by compressing a sequence of spheroidal homoeoids into a surface distribution of matter. The resulting integral equation is then essentially Abel's equation, and the mass distribution can be obtained as an explicit integral of the rotation curve. A family of analytic rotation curves is introduced, and the necessary constants relating to the mass distribution have been tabulated for two members. Aside from observational consistency, the existing determinations of the total mass must, in general, be adjusted so that the mass refers to the entire galaxy, and not just to the mass in homoeoids out to a certain point (often the point of the observation farthest from the center of the galaxy). The determinations of the mass of M31 by Babcock, Wyse and Mayall, Schwarzschild, Lohman, Schmidt, and this investigation can be shown to be mutually consistent with all of the adjusted values lying between 3.5 and $4.0 \times 10^{11} M_\odot$ for a distance of 600 kpc. The theory may also be applied to the problem of the mass of the Galaxy. From the radio observations, a simple expression for the mass of the Galaxy in homoeoids interior to the sun $M(R_0)$, can be obtained with H_0 and R_0 left as undetermined parameters throughout. This expression can be written entirely in terms of R_0 and goes essentially as R_0^3 . With the uncertainty in R_0 , the value of $M(R_0)$ is very uncertain. Further, the existing rotation curve leaves the value of the mass in homoeoids exterior to the sun ill determined. The combination of these two effects means that the total mass of the Galaxy is known only as to order of magnitude.

The Double-Lined Binary Alpha Octantis. W. BUSCOMBE AND P. M. MORRIS, *Mount Stromlo Observatory*.—Radial velocities have been measured from 24 new spectrograms of HD 199532, which together with eight measures previously published from Lick Observatory, make possible a solution of the orbit. The dispersion of both sets of plates is about 36 Å/mm at $H\gamma$. On six of the Mount Stromlo spectrograms, double absorption lines are resolved. The measures indicate velocity curves of the same amplitude (47 km/sec) corresponding to stars of equal mass. The period is 9.073 days, and the system velocity +45 km/sec. The MK classes are F4 III–F5 III. The eccentricity is 0.39 and primary periastron in longitude $276^\circ 13'$ at JD 2435302.404. The mass-function 0.304 combined with masses each twice the sun's, corresponding to the luminosities,

would indicate an inclination 23° between the normal to the plane of the orbit and our line of sight. As the projected semi-major axis is 5.4×10^6 km, and the stellar radii are 3×10^6 km, only very shallow grazing eclipses may be possible.

Curve of Growth of C_2 Absorption Bands Applied to the Problem of the C^{12}/C^{13} Abundance Ratio. JOHN L. CLIMENHAGA, *Victoria College*.—The curve of growth for a section of the 1,0 C_2 Swan band has been determined to try to obtain an improved value of the C^{12}/C^{13} abundance ratio in the atmospheres of the cool carbon stars. The Minnaert semiempirical equation $1/R_\lambda = 1/R_c + 1/\tau_\lambda$ was used to compute profiles for the head-forming regions of the $\lambda 4737$ $C^{12}C^{12}$ and $\lambda 4745$ $C^{12}C^{13}$ Swan bands for different numbers of absorbing molecules, first assuming no C^{13} is present, and secondly assuming for the abundance ratio C^{12}/C^{13} the three values 100, 20, and 4. There is good general agreement between computed and observed band profiles. Curves of growth were constructed for the head-forming region of the $C^{12}C^{12}$ band. Equivalent widths of the bands in stellar spectra all fall beyond the linear part of the curve of growth. Data from single-prism Victoria spectrograms of eight R-type stars showing $C^{12}C^{13}$ bands was used in conjunction with the curve of growth and a mean value of 5.8 was found for C^{12}/C^{13} . By using tracings of five high-dispersion spectra (kindly made available from Mt. Wilson and Palomar, and Victoria observatories) of two of these R-type stars and the curve of growth, a mean value of 4.7 was found for C^{12}/C^{13} . It was for the above stars that McKellar in 1948, neglecting curve-of-growth effects, obtained a ratio of about 3.5. The present values are in better agreement with the value of 4.6 determined from nuclear theory to represent the equilibrium ratio of C^{12}/C^{13} when the CN cycle is in operation. From additional high-dispersion spectrograms, abundance ratios of 8 and 16 were found for the N-type stars 19 Piscium and DS Pegasi. These values compare with the minimum ratio of about 10 reported for 19 Piscium by Wyller in 1958.

On the Reversal of the Sense of Rotation in Solar Microwave Bursts. M. H. COHEN, *Cornell University*.—The high-frequency theory of magneto-ionic mode coupling predicts a frequency, f_c , for critical coupling in a quasi-transverse (QT) region. If $f^A \ll f_c^A$ there is weak coupling. One mode cannot excite the other, so that a wave composed of only one mode has its polarization change as the medium changes. If this wave passes through a QT region such that the longitudinal component of magnetic field is oppositely directed on the two sides of the region, its sense of rotation will be reversed. If $f^A \gg f_c^A$ there is strong coupling, and the polarization is constant across the QT region. The critical frequency is given by $f_c^A = 10^{17} NSB^3$, where N = electron density (cm^{-3}), S = scale of magnetic field (cm), and B = strength of magnetic field (gauss). It has been observed (Tanaka and Kahinuma, 1959) that about $\frac{2}{3}$ of the wide-band polarized microwave solar bursts have a sense of rotation which reverses at about 4000 Mc. It is suggested that this may be explained by the passage of the ray through a QT region in the lower corona, above an active region.

Winds in the Upper Atmosphere. A. F. COOK, II, *Harvard College Observatory*.—Various types of running waves including those discussed by C. O. Hines are considered as possible explanations of the observed distortions of meteoric trains. The Coriolis force is included so that the results apply to all frequencies. However, at periods much shorter than twelve hours and at meteoric heights the Coriolis force introduces only a minor perturbation. In addition to the gravity waves discussed by Hines, highly modified sound waves may also occur. Hines' results for the gravity waves are recovered, viz., nearly horizontal velocities of motion of the air for nearly vertical propagation of the waves. The modified sound waves corresponding to the observed wavelengths of distortions of meteoric trains require periods so short that the corresponding variations with time in the distortion of meteoric trains should have been observed. Since they are not

the conclusion follows that only the modified gravity waves may be present.

Radiative and Conductive Opacities for Stellar Mixtures. A. N. COX AND D. D. EILERS, *Los Alamos Scientific Laboratory*.

—A program for the calculation of radiative and conductive opacities is in progress at the Los Alamos Scientific Laboratory. This work is appropriate because of new hydrogen-like bound-free and free-free gaunt factors of Karzas and Latter and because accurate opacities are needed for modern stellar models. Checks are being made of all the opacities given by Keller and Meyerott and by Zirin. Some of the opacities for this program are being calculated by considering the electronic occupation of individual ions instead of the usual methods which consider only the average atom of each element. Comparisons show that the previous radiative opacities are generally accurate to about 10% except in isolated cases. Conductive opacities are calculated by a method slightly modified from that described by Mestel. Within 10% the results for the Russell mixture agree with conductive opacities given by Lee. Errors in the values for radiative and the combined radiative and conductive opacities should be less than 10% if bound-bound absorptions are negligible as assumed.

Programs for Automatic Reduction of UBV and $H\beta$ Photoelectric Measures. D. L. CRAWFORD, *Dyer Observatory, Vanderbilt University*.

—Programs have been written for automatic reduction of photoelectric observations, utilizing an IBM 650 computer system. Three separate programs are available. The first is a general one for reduction of UBV observations. The second is a program especially written to determine extinction coefficients, and to keep close check on any variation of these coefficients. The third is a general reduction program for $H\beta$ narrow band photometry. An attempt has been made to keep all three programs as general and adaptable as possible, and all are optimized for efficient use of machine time. Some special features and techniques are pointed out. All three programs are available from the Vanderbilt University Computing Center at cost.

Color Classification of Galaxies. G. DE VAUCOULEURS, *Harvard College Observatory*.

—Colors of about 150 galaxies in the UBV system are used to define a standard "main sequence" in the $U-B$, $B-V$ diagram. Departures from the main sequence arise from ultraviolet excess in some peculiar galaxies (e.g., Mayall's nebula) and in the emission nuclei of some spirals (e.g., Seyfert's galaxies). Many of the other "blue" galaxies described by Haro are merely late-type irregulars which do not depart significantly from the main sequence. The color distribution in normal galaxies is analyzed as a function of tilt, galaxy type, and absolute magnitude. After correction for reddening caused by tilt effects the colors of spirals and irregulars are closely correlated with morphological type (Sa to Im) and with the ratio $A/D(O)$ of the field aperture to the reduced or "face on" diameter $D(O)$. This correlation can be used for an objective quantitative color classification of galaxies in good agreement with spectroscopic criteria. For ellipticals (E) and lenticulars (SO) there is a large variation of color with absolute magnitude, which can be used for distance determinations after correction for red-shift effects. Residual color excesses in low galactic latitudes permit a determination of interstellar absorption for individual objects of well-defined morphological type.

Flares of July 16, 1959. H. W. DODSON AND E. R. HEDEMAN, *McMath-Hulbert Observatory*.

—Two flares of importance 3 and 3⁺, respectively, occurred on July 16, 1959 in the north central part of the solar disk. They were separated in time by about five hours. The two flares differed greatly in their radio frequency emission. The earlier flare was accompanied primarily by a type II or slow-drift burst. The second was one of the relatively few flares known to be associated in time with great emission at centimeter wavelengths, with great con-

tinuum radiation at radio frequencies, and with enhancement of high energy particles in the neighborhood of the earth. For these two flares, the time intervals between start and maximum were similar, being 23 and 21 minutes, respectively. Although these values are longer than average for flares in general, they are not abnormally long for flares of importance 3. During the second of the two flares, spectroheliograms were made by systematic changes of wavelength throughout 6A of the spectrum centered on $H\alpha$. These spectroheliograms revealed numerous hydrogen absorption features, some with ascending and some with descending motions. In the late stages of the flare, spectroheliograms taken to the redward of $H\alpha$, showed an extensive system of curved dark features which may be loop-type prominences in projection against the disk. Comparison revealed a conspicuous difference in the locations of the two flares. Portions of the flare with the great centimeter and continuum radiation occurred directly over the umbrae of large spots. No portion of the earlier flare, which did not have this type of radio-frequency emission, appeared over the umbra of a large spot. Similar comparisons have been made for a small number of other flares. The association between very great centimeter wavelength radio emission and close proximity of $H\alpha$ flare and large spot umbra is sufficiently good to warrant further investigation.

Survey of Number of Flares Observed during the IGY.

H. W. DODSON AND E. R. HEDEMAN, *McMath-Hulbert Observatory*.

—In the McMath-Hulbert Observatory working list of world-wide flares there are more than 6700 solar events during the IGY for which at least one observer estimated the importance to be ≥ 1 . According to reports to World Data Centers the flare patrol was gratifyingly complete and uniform. However, examination of the starting times of the reported flares reveals evidence for a serious lack of homogeneity in the IGY flare data. Approximately twice as many flares, ≥ 1 , were reported per hour from 05^h to 16^h UT as during the remainder of the Universal Day. This strong dependence on UT exists in the flare data for each month of the IGY. Examination of the patrol hours and flare reports for May and July 1958 for each of the 19 $H\alpha$ cinematographic patrol stations shows that the principal photographic patrol stations fail to confirm the very high rate of flare occurrence for 05^h to 16^h UT that appears in the total IGY data. Furthermore, for the hours 17 to 04 in the Universal Day the IGY flare reports are based primarily on the cinematographic patrol. Comparison of the number of flares and subflares indicates that in the IGY data for the hours 05 to 16 UT many flare events are listed as flares that probably would have been classified as subflares by the principal cinematographic observers.

Remarks on the Radio Emission from the Gamma Cygni Nebulosity. F. D. DRAKE, *National Radio Astronomy Observatory*.

—The existing radio data suggest that the radio emission from the Gamma Cygni nebulosity has the spectrum of an HII region. It is shown, using Stromgren's original relations, that the radio flux predicted for the Stromgren sphere of an F8 Ib star is adequate to explain the observed radio flux from Gamma Cygni. Thus the strong radio emission and bright nebulosity are not unusual, despite the late spectral type. It appears that the existence of a bright nebula close to Gamma Cygni is a result of the star's peculiar space motion, which has carried the star into a dense dark nebula. The resulting ionization has exposed portions of the dust cloud to quantitative study. Densities greater than 1000 atoms/cc probably are present in the cloud.

Detection of Discrete Solar Radio Emission Sources during the October 2, 1959 Partial Eclipse. S. EDELSON, C. R. GRANT, AND H. CORBETT, *Radio Astronomy Branch, U. S. Naval Research Laboratory*.

—On October 2, 1959, observations of the partial solar eclipse were made at the Naval Research Laboratory. Variations in the solar flux were recorded at 0.43-, 3.15-, and 9.4-cm wavelengths as the sun was gradually uncovered by the moon. H-alpha photographs of the

event were made simultaneously. Analysis of the 3.15- and 9.4-cm records indicate that the times at which abrupt changes in the slope of the flux curves occur, coincide with the times of intersection of the moon's limb with the H-alpha plage regions. The times of slope changes at 3.15 cm preceded the times of slope changes at 9.4 cm, showing the well-known height wavelength relationship. Assuming the radio sources extend radially above the H-alpha plages, the average minimum heights above these regions for six radio sources were found to be 27 000 and 40 000 km for 3.15 and 9.4 cm, respectively. The size and brightness temperature of these radio sources may be determined from the observed motion of the moon across each region and the measured flux increases during transit. Preliminary calculations indicate that the radio source size is of the order of 0.8 minute of arc; and that the average brightness temperatures for 3.15 and 9.4 cm are 1.8×10^6 ° and 6.8×10^6 K, respectively.

Line Blending in Stellar Spectra. J. H. EVANS, L. HALLGREN, V. L. PETERSON, D. C. SCHMALBERGER, and MARSHAL H. WRUBEL, *Astronomy Department, Indiana University*.—Earlier theoretical studies of line blending have been restricted to simple cases because of computational limitations. The availability of high-speed digital computers now makes it possible to include the dependence on depth of all the physical quantities, such as the number of absorbers and the continuous opacity, which contribute to the profile of the blend. Preliminary studies are being made with the IBM 650 of the Indiana University Research Computing Center. The application of these computations to the interpretation of blends produced in the solar atmosphere will be discussed.

The Effect of Nonsphericity on the Interstellar Extinction Curve. J. M. GREENBERG, A. MELTZER, and J. C. PEDERSEN, *Rensselaer Polytechnic Institute*.—An approximate method of calculation has been applied to determine the effects of nonsphericity on the difference between the wavelength dependence of the extinction as a function of the kind of orientation of the particles. Using a reasonable distribution of particle sizes such as that of Oort and van de Hulst, one finds different deviations from the λ^{-1} law in the short wavelength region depending on whether one views along or perpendicular to magnetic field directions. The orientation mechanism which is assumed is that of Davis and Greenstein. An analysis of existing observational data is being made for the purpose of comparing with the qualitative features of the calculations.

This work was supported by the National Science Foundation.

Measurements on the Extinction and Polarization of Light by Nonspherical Particles. J. M. GREENBERG and N. E. PEDERSEN, *Rensselaer Polytechnic Institute*.—A microwave analog method has been developed to give the total cross sections, angular distributions, and polarization of light scattered by nonspherical particles. Some data pertaining to the interstellar absorption and polarization are presented, and the effects on the interpretation are discussed. It is shown that the polarization and wavelength dependence of the extinction can probably be used somewhat independently to determine the nonsphericity of the particles. Some interesting variations of scattering cross sections with orientation are discussed.

This work was supported by grants from Research Corporation and the National Science Foundation.

Photometry of the Brighter Stars in the Scorpius Region. R. H. HARDIE, *Dyer Observatory, Vanderbilt University*.—Three-color photometry of stars earlier than AO (HD type) located north of -30° declination in the Scorpius-Centaurus Association is presented. These include stars near β Sco, δ Sco, π Sco, ρ Sco, σ Sco, τ Sco, 13 Sco, and τ Lib, which form the northern end of the long extended region covered by the association. The color-magnitude diagram is discussed in relation to the absolute magnitudes of the stars.

The Redshift. GERALD S. HAWKINS, *Boston University and Harvard College Observatory*.—The spherically symmetric metric of general relativity has the polar form,

$$ds^2 = -e^{\lambda} dt^2 - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 + e^{\nu} dr^2. \quad (1)$$

In a static fluid of density ρ , pressure p , the components of the energy-momentum tensor become

$$8\pi p = e^{-\lambda} [(\nu'/r) + (1/r^2)] - 1/r^2, \quad (2)$$

$$8\pi \rho = e^{-\lambda} [(\lambda'/r) - (1/r^2)] + 1/r^2, \quad (3)$$

where $\nu' = d\nu/dr$. For a homogeneous fluid we may take $p + \rho = 0$. By solving for λ and ν the metric becomes, in cgs units:

$$ds^2 = \frac{-dr^2}{1 - (8\pi/3c^2) G\rho r^2} - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 + [1 - (8\pi/3c^2) G\rho r^2] dt^2. \quad (4)$$

This is the general relativity line element for a static universe and it includes the effect of the material in the universe of mean density ρ . Since this is a static solution,

$$\delta t/\delta s = [1 - (8\pi/3c^2) G\rho r^2]^{-1/2}. \quad (5)$$

This relates the observed period δt to the interval δs at rest, and the wavelength λ observed from a source at a distance r is increased in the ratio

$$\lambda/\lambda_0 = 1 + (4\pi/3c^2) G\rho r^2. \quad (6)$$

Thus, the following redshift law is predicted:

$$(\delta\lambda/\lambda) = (4\pi/3c^2) G\rho r^2. \quad (7)$$

A redshift is therefore a necessary property of a static universe and is related to the difference gravitational potential between galaxies. As a corollary, if the observed redshifts agree with this prediction we may conclude that the universe is indeed static and the concept of a large scale expansion becomes unnecessary. The gravitational redshift is proportional to the mean density ρ and to the square of the distance, in contrast to the linear relation of Hubble. A good fit is obtained with the observational data out to a distance of 10 megaparsecs taking the mean density as 3×10^{-26} g cm $^{-3}$ and the Hubble constant as 180 km sec $^{-1}$ /megaparsec. The deviation from an r^2 law beyond 10 megaparsecs is of interest. The deviation occurs at the boundary of the super cluster where the concentration of galaxies begins to decrease. The linear redshift law would be approximated if we assumed that the density ρ decreases by a factor of 10 beyond the edge of the super cluster. Since these densities are possible we might take a stationary universe as a working hypothesis. It is of interest to note at this stage that there is an approximate radiation balance in the universe; a galaxy such as M31 receives almost as much radiation from the universe as it emits. The hypothesis of a stationary universe leads to other conclusions. The lifetime of the universe may be increased by several orders of magnitude beyond the current estimates. The mean density of clusters of galaxies must be less than 7.12×10^{-22} divided by the square of the diameter in megaparsecs. The shift is progressively red, at no distance would we expect it to become systematically blue. The redshift from members of a cluster of galaxies should be greater than that from field galaxies because of the gravitational potential of the cluster.

The Older Meteor Streams. G. S. HAWKINS and R. B. SOUTHWORTH, *Harvard College Observatory*.—A criterion, distinguishing members of a meteor stream from nonmembers, has been established as follows. A function $D(A, B)$ of the orbits of any pair of meteors A and B has been chosen to represent the difference between the orbits. The function $D(A, B)$ is approximately the velocity increment that perturbs one orbit into the other, where velocity is measured in units of the speed in a circular orbit. Within known streams, the difference $D(M, N)$

between a mean orbit M and the orbits of member meteors N has a mean value of 0.09, and more than 90% of the values are ≤ 0.20 . It seems reasonable to adopt $D(A, B)$ as a criterion for the identification of members of a stream. We have found all pairs of orbits for which $D \leq 0.20$ within a random set of 360 meteors photographed with the Baker Super-Schmidt cameras. Thirteen percent of the set had previously been known to belong to "major" streams, i.e., those streams of high hourly rate. Forty percent more of the meteors were now found to be associated into 32 minor streams, of which only 6 had previously been recognized among photographic meteors. A control experiment, seeking associations among random artificial meteors, shows that 80% or more of the minor streams found are genuine. The internal dispersion of the minor streams approximated twice the dispersion in major streams. The groups form a new class of streams. They have very broad radiant areas and protracted showers at very low hourly rates. We may recognize these groups as streams which have undergone more dynamical aging processes than the major streams, but which have not wholly dispersed into sporadic orbits.

A New Spectrum of CH_2 in the Region 6000–9000 Å.

G. HERZBERG, *National Research Council, Ottawa, Canada.*—

A year ago a spectrum was found [G. Herzberg and J. Shoosmith, *Nature* **183**, 1801 (1959)] near 1400 Å which on the basis of its fine structure could be definitely assigned to CH_2 . More recently, under conditions very similar to those used for obtaining the 1400 Å group (flash photolysis of CH_2N_2 at partial pressures of about 0.02 mm in the presence of a large excess of inert gas), a new spectrum was found in the region 6000–9000 Å which consists of a large number of absorption bands with wide and somewhat complicated fine structure. The spectrum is similar in appearance to the α bands of NH_2 . A preliminary analysis suggests strongly that the lower state is the expected lowest singlet state $^1A_1$ of bent CH_2 , while the lower state of the 1400 Å group is the $^2\Sigma^-$ state of linear CH_2 . The existence of two kinds of CH_2 , a bent and a linear form corresponding to the lowest singlet and triplet state, respectively, is in accordance with what might be expected from theory. From the slight difference in the conditions of production of the two absorption spectra of CH_2 it appears likely that the $^2\Sigma^-$ state is the lowest. Because of the low excitation energy of the first singlet state above the triplet ground state it is likely that the red bands will turn out to be of some astrophysical interest. They might be expected to be observable in emission in the spectra of comets, and in absorption in the spectra of the outer planets and of low temperature carbon stars. In order to assist in possible identifications, a table of the strongest lines of the new CH_2 bands will be presented.

An Accurate Position Determination for a Strong Component of Cygnus X. R. W. HOBBS (introduced by FRANK D. DRAKE)

Case Institute of Technology.—Results of a study made at the National Radio Astronomy Observatory, Green Bank, West Virginia, show that a strong radio source in Cygnus X coincides in position with a nebulosity apparently associated with the F8 Ib star γ Cygni. Observations were made with the 85-ft parabolic antenna which has a beamwidth of 7 minutes of arc at the wavelength used, 3.75 cm. Observations consisted of right ascension and declination drifts across the position of γ Cygni. Position calibrations of the antenna were made using the position of Cygnus A as a standard; temperature calibrations were made using a $1^\circ K$ source in the receiver. The Naval Research Laboratory absolute flux measurement of Cassiopeia A was used to determine antenna aperture efficiency. The right ascension and declination drifts were reduced, and Gaussian curves fitted to the results by least squares. These gave the position of maximum antenna temperature at right ascension $20^h 20^m 33^s \pm 1^s$ and declination $40^\circ 2.9' \pm 1.0'$ (1950.0). The probable errors are those of the position standard, Cygnus A. The position of the maximum is 1.1 minutes east and 3 minutes

south of γ Cygni, very near a nebulosity apparently associated with the star.

The Critical Inclination Case of the Motion of an Artificial Satellite. GEN-ICHIRO HORI, *Yale University Observatory.*—

The ordinary procedure in developing the perturbations in the motion of an artificial satellite by a method of canonical transformations is to develop the determining function in powers of the small parameter that is a factor of the second harmonic in the earth's potential. If the inclination is close to the critical inclination, $I_c = \cos^{-1}[1/(5)^{1/2}]$ a small divisor arises which may make the developments illusory. It is shown that this difficulty may be avoided by developing the determining function in powers of the square root of the small parameter. The solutions in the vicinity of the critical inclination may be divided into three types: the libration case, the transition case, and the nonlibration case, depending on the proximity of the inclination to its critical value. The fourth harmonic of the earth's potential is included in the solution because it turns out to be equally important as the second harmonic in this aspect of artificial satellite motion. In a preliminary study of the problem, results valid as far as the square root of the small parameter have been obtained; parts of higher order have been omitted. The solutions are expressed with the aid of elliptic integrals in all cases; in the transition case the elliptic integrals degenerate to elementary functions.

Individual Characteristics of Meteor Families. LUIGI G. JACCHIA, *Smithsonian Astrophysical Observatory.*—

An analysis has been made of the heights of appearance of 392 Super-Schmidt meteors. The light curve of all meteors was accurately determined and reduced to a standard meteor distance of 100 km. To eliminate instrumental and transparency effects, the "height of appearance" of a meteor was defined as the height at which its absolute photographic magnitude reached $+2.5$ on the ascending branch of the light curve. When this quantity, $H_{2.5}$, is plotted against the apparent meteor velocity, two effects emerge: (a) Meteors which reach greater maximum brightness appear at greater heights (about 1.5 km higher for each magnitude); (b) Meteors with long-period orbits appear at systematically greater heights than meteors of the Jupiter family; the difference is about 3 km. The first effect is predicted by classical meteor theory. The second effect can be connected with the individual characteristics of shower meteors previously found by the author.

The Basic Escape Rate of Stars from Clusters. IVAN KING, *University of Illinois Observatory.*—

In the escape of stars from an isolated cluster the basic mechanism is the relaxation of a velocity distribution as a result of stellar encounters. All estimates of the rate of escape of stars therefore contain a multiplicative factor that expresses this relaxation rate. Short of solving the entire problem of the dynamics of an isolated cluster, the best method of estimating this basic escape rate is to solve an idealized problem that represents the relaxation process without any further dynamical complications. This idealized problem is to find a velocity distribution in which encounters maintain a steady state, subject to a cutoff at the escape velocity. As stars disappear at the cutoff, the total number of stars decreases while the shape of the velocity distribution remains unchanged. The problem has been solved previously under the assumption that the stars under consideration encounter another group of stars having a Gaussian velocity distribution. The present paper removes this restriction and treats the case of a group of stars encountering each other, so that the unknown velocity distribution in the Fokker-Planck equation appears not only in the usual derivatives but also in the encounter integrals. The usual separation-of-variables technique can be used, but a scale change in the velocities must be included, in order to conserve total energy as high-speed stars disappear across the cutoff. The resulting solution gives an escape rate about 50% higher than that recently found by Spitzer and Härm. The escape rate depends somewhat on the

way in which energy is fed into the velocity distribution by processes such as contraction of the cluster.

The Ohio State University 360-Foot Radio Telescope.

JOHN D. KRAUS, *Ohio State University Radio Observatory*.—The telescope consists of a standing parabola 360 ft long by 70 ft high and a tiltable flat reflector of approximately the same dimensions. The parabola is fixed in position, the celestial radio waves being deflected into it by the flat reflector. Electrical tests of the design were begun in 1953 using a scale model. Through a grant from the National Science Foundation construction of the large telescope was begun in 1956. The parabola was completed in 1958 and the tilt flat reflector is now also substantially complete. It is hoped that the remaining construction will be finished late in 1960. A number of the unusual construction features are described. The telescope is being built by the Ohio State University on a site provided by the Ohio Wesleyan University near the Perkins Observatory south of Delaware, Ohio. The telescope is designed to operate at wavelengths between 15 cm and 15 m, a range in wavelength of 100 to 1. A program of sky background mapping, precision position measurement of radio sources and their detailed spectra are planned for the new telescope. Designs are being made to use wide-band feed antennas and tunable receivers so that the spectra of radio sources can be measured rapidly and accurately over the 100 to 1 range in wavelength. The fact that the prime focus is at ground level makes it feasible to employ an elaborate feed antenna and to install low-noise receivers right at the feed point without regard for weight or size. Instrumentation for hydrogen line observations also is to be installed.

The Universality of the Initial Luminosity Function.

D. NELSON LIMBER, *Yerkes Observatory*.—The universality of an initial luminosity function based upon the galactic clusters and the solar vicinity is examined with regard to its implications for the mass-to-light ratios for stellar systems. For this purpose the times that stars spend on and near the main sequence are derived as a function of stellar mass from a discussion of the available data for individual stellar models. These results are then used to calculate upper limits to the mass-to-light ratios for stellar systems as functions of the ages of the systems—on the assumption that an initial luminosity function of the usual form has been operative. The observational data relating to the mass-to-light ratios for galaxies and globular clusters are then analyzed, and the corresponding values for their mass-to-light ratios are obtained. These observational values are compared with the calculated upper limits, and it is found that ages greatly in excess of 12 billion years would be required for many galaxies in order for the data to be consistent with the adopted form of the initial luminosity function. The evidence appears to strongly support the view that the initial luminosity function has at times differed in a very significant way from its assumed form. It follows that the form of the initial luminosity function is sensitive to at least certain of the physical parameters that describe the pre-stellar medium—parameters such as density, temperature, turbulent and magnetic states, and chemical composition.

Evidence of a Solar Corpuscular Influence on Large-Scale Weather Phenomena.

N. J. MACDONALD AND W. O. ROBERTS, *High Altitude Observatory, University of Colorado*.—Statistical evidence from three successive winter half-years strongly indicates that when the earth is bombarded by unusually intense solar corpuscular emission, certain low-pressure troughs in the 300-mb circulation are subsequently amplified. The troughs so affected enter or are formed in the Gulf of Alaska-Aleutian Islands area on the second, third, or fourth days after the start of the corpuscular increases. The trough amplifications maximize a variable number of days later, and in different locations, which may explain why the result was not apparent to earlier workers. The same result has been found independently, at about the same level of significance, in

each of the three winters treated separately. For the three half-years grouped together the probability of so strong a chance association is less than 10^{-6} .

A Direct Determination of Neutral Hydrogen between the Earth and the Sun.

P. MANGE, J. D. PURCELL, AND R. TOUSEY, *U. S. Naval Research Laboratory*.—Profiles of the Solar Lyman-alpha line obtained by means of a rocket-borne spectrograph exhibit a deep narrow absorption line superimposed on a broad shallow central reversal. The observed width of the core at half-maximum, 0.05A, even without correction for instrumental broadening, indicates absorption by hydrogen at a temperature of no more than 3300°K. The absorption core is therefore attributed to hydrogen outside the solar atmosphere. From the observed depth and breadth of the absorption, the total hydrogen between the sun and the E-region of the earth's atmosphere is calculated to be 3×10^{22} atoms/cm² column, with an estimated accuracy factor of 2. The absorption curves are examined for compatibility with suggested distributions of hydrogen in the terrestrial atmosphere, taking into account molecular diffusion and the variation of temperature with altitude.

Possible Absorption Lines in Spectra of Three Supernovae.

DEAN B. McLAUGHLIN, *The Observatory University of Michigan*.—A number of hazy absorption-like minima were measured on two or more Lick Observatory spectrograms of each of the three supernovae: SN (1954) NGC 5668, SN (1956) NGC 3992, and SN (1957) NGC 4374. A Mount Wilson-Palomar plate confirms most of the features in the first- and last-named stars. In general appearance the three spectra are nearly identical and of type I, with the usual pattern of broad diffuse maxima of radiation and no evident deviations from the type. They differ considerably from the peculiar type I object SN (1954) NGC 4214. The patterns of "absorption" differ appreciably, but in all three spectra nearly all "lines" give fairly consistent large negative displacements when identified with lines of HeI, HeII, CII, NII, OII, or other ions found in hot stars. Hydrogen lines are weak or absent. Composition of these "absorption spectra" thus resembles that of SN (1954) NGC 4214 (McLaughlin 1959). In the latter, however, some lines assigned to HeI appear in great strength. These are not outstanding in the three spectra discussed here. However, common to all four was the broad and deep minimum centered about 3820 A, which may be due largely to HeI 3889 whose lower level is metastable. Apparent velocities are in the range -5000 to -7000 km/sec. Identifications appear most satisfactory in SN-NGC 3992, in which nearly every line can be assigned an origin consistent with a hydrogen-poor O-B spectrum. The "absorptions" are fewest, weakest, and least conclusive in SN-NGC 4374 but, so far as they go, they can be interpreted similarly. The author is grateful for the use of spectrograms taken at Lick and Mount Wilson-Palomar Observatories.

On the Fine Structure of Solar Prominences.

D. H. MENZEL AND J. G. WOLBACH, *Harvard College Observatory*.—Solar prominences are not uniform clouds of luminous gas. Observations have clearly shown them to possess filamentary structure. In "hedgerow" prominences these filaments present the appearance of tangled skeins of thread. In various prominences associated with sunspots the filaments assume distinctive forms of which loops are the simplest and the most characteristic. Large scale coronagraph records from Sacramento Peak Observatory have disclosed a still finer structure existing in the filaments themselves. Two types apparently exist. For example a hazy thread, curving gracefully from the upper corona toward the solar surface, is not continuously luminous along its length. High magnification shows that the filament really consists of closely spaced hazy dashes, with the length of the dash roughly perpendicular to the filament. In some complex prominences, the dashes on one filament appear as continuations of those of the adjacent filament. Occasionally the luminous pattern suggests a

system of two orthogonal coordinates, the one defined by the filaments and the second by the luminous dashes perpendicular to the filaments. This type of pattern often appears in the 5303 corona. The pattern and behavior suggests the occurrence of magnetohydrodynamic shock waves, arising from some quasi-periodic source near the base of the prominence. If the filaments run parallel to the magnetic lines of force, the orthogonal pattern may be associated with currents. Alternatively the pattern may well be attributed to magnetohydrodynamic instability. The second type of fine structure refers to the loops themselves, whose quasi-circular filament consists of large numbers of parallel threads, whose diameters are less than the resolving power of the instrument. Here the forms clearly suggest the presence of electric currents along the loops, with instabilities arising from the "pinch effect."

Measurements of the K-Line in Spectra of Sunspots.

ORREN C. MOHLER, *McMath-Hulbert Observatory*.—The structure of the center of the K-line in spectra of sunspots has been observed on a number of occasions. The structure of the K-line exactly over the umbra most frequently shows a double reversal much like that present in the normal solar disk with the difference that the reversal in the umbra of a sunspot consists of two narrow components separated by about $\frac{1}{4}$ to $\frac{1}{5}$ the separation of the emission components that appear in normal disk spectra. The next most frequent structure visible in sunspots is a featureless line with a width approximately double that of the reversed emission components. In a small number of spots the structure is so completely disorganized that no general features have been found. In a normal plage region near the center of the disk the separation of the brightly reversed components of the K-line averages less than 0.75A. The separation varies linearly from its value in the adjacent plage to the narrow separation (about 0.090A) observed in the umbra of the sunspot. These values should be compared with the separation for the normal disk of about 0.600A. The intensities of the emission components in the sunspot spectra are very low, approximately $\frac{1}{4}$ the intensity of the K3 emission components in the undisturbed center of the solar disk. Often the emission seems to be completely absent unless special care is used in making the photographic observations.

Motions of the Gas near the Nucleus of M31. GUIDO

MÜNCH, *California Institute of Technology*.—Some results of the observation of [OII] emission in the neighborhood of the nucleus of the Andromeda Nebula are presented. With the prime focus spectrograph of the Hale reflector at a dispersion of 66 Å/mm, the [OII] doublet at $\lambda 3726-28$ has been resolved and detected out to a distance of 50" from the nucleus, with the slit at various position angles. While the individual components of the doublet appear narrow, they show sudden large variations in velocity superposed on the rotational pattern of the system as a whole. Because of the underlying absorption spectrum, the true value of the velocities can not yet be found accurately, but, on the whole, the motion of the gas seems to have a well-defined outward motion, amounting to 50 km/sec at a distance of 200 pc from the nucleus. The noncircular nature of the motion is most clearly observed with the slit along the minor axis, where all rotational effects should vanish. There are reasons to interpret these observations in terms of motions taking place predominantly in directions confined to the symmetry plane of the system.

Some Remarks Relating to the Classification of Spectra from Objective Prism Plates Which Include the Ultraviolet Region. J. J. NASSAU AND C. B. STEPHENSON, *Warner and Swasey Observatory*.

—The purpose of this investigation is a first step in the survey of stars of high luminosity in the northern sky, a project jointly undertaken by the Hamburg and Warner and Swasey Observatories. Slettebak and Stock have published criteria derived from objective prism spectra utilizing the UV region and particularly the Balmer discontinuity. A similar study has been undertaken by us with

our newly acquired objective prism which records spectra to about 3200Å. In the collection of standard MK-types, we have included a number of peculiar stars with the hope of augmenting their classification criteria from the UV region. Our results for the OB stars and the other highly luminous classes are, in general in good agreement with the previous investigation. Specifically, luminosity classes Ia, Ib, and II may be recognized between B7 and G0, and class III is recognizable from B7 to A5 and again at G0. The results for peculiar stars are as follows: The UV proves to be particularly useful for the identification of the common types of white dwarfs and is helpful in certain types of variables as, for example, R CBr-type and SS Cygni at minimum light. However, a number of peculiar stars appear normal at the dispersion used, even far into the ultraviolet. From the limited number of standards available, F-type subdwarfs fail detection. RR Lyrae appears as a normal A-type of luminosity Ib to II. The Milky Way survey includes plates in the region between 5900 and 7000Å in order to eliminate early type objects which simulate high luminosity OB-stars in consequence of Balmer emission. These plates prove useful in the detection of planetary nebulae and stars showing emission lines, also carbon, early M- and S-stars with greater certainty than the early infrared surveys. The space depth reached from these objects is comparable to the infrared.

The Frequency of Crater Diameters in Mare Imbrium.

ERNST J. ÖPIK, *Department of Physics, University of Maryland (on leave from Armagh Observatory, North Ireland)*.—Rim to rim diameters of 812 craters from 0.6 km up have been measured over an area of 465 000 km² in Western Mare Imbrium, on a print of the Mount Wilson photograph of September 15, 1919. The data are complete down to a diameter of 1.2 km. By assuming a ratio of projectile to crater diameter of 0.05, corresponding to an impact velocity of 20 km/sec (Öpik 1958), the observed cumulative number (N_{obs}) of projectile diameters is compared with a theoretical number of impacts (N_{theor}) during 4.5×10^9 years, calculated on the assumption that the frequency of impacts has been constant and equal to the present rate (Öpik 1958). The agreement is good except for the large craters.

Projectile diam, km	0.060	0.124	0.270	0.64	1.72	3.53
N_{obs}	733	208	35	10	3	1
N_{theor}	1050	202	35	5.0	0.44	0.10

It seems that the frequency of stray objects in the neighborhood of the earth's orbit has not varied greatly since the formation of the Mare, and that the age of the latter compares with that of the solar system.

Orbital Elements for the Spectrographic Binary U Ophiuchi, HD 156247. JOSEPH A. PEARCE, *Dominion Astrophysical Observatory*.

—A new determination of the spectrographic orbital elements of this eclipsing variable was made from a series of forty spectrograms (dispersion 30 Å/mm at $H\gamma$) taken by the author in 1935. The orbital elements are: $T = \text{HJD. } 2428\,054.881 \pm 0.1393$; $P = 1.6773458$ days; $e = 0.012 \pm 0.0020$; $\omega_1 = 306^\circ \pm 30^\circ$; $\omega_2 = 126^\circ \pm 30^\circ$; $V_0 = -10.8 \pm 0.64$ km/sec; $K_1 = 180.0 \pm 1.24$ km/sec; $K_2 = 199.4 \pm 1.43$ km/sec; mass ratio = 0.90 ± 0.009 . The probable error of a single observation of the primary component, spectral type B4, was ± 3.5 km/sec while that of the B5 secondary star was ± 4.5 km/sec. The provisional elements of Plaskett derived with less precision from fewer observations in 1919 are in good agreement with the above elements, but those of Abrami, deduced in 1957 from the Asiago observations which suggested a change in the systemic velocity and a decrease in the amplitude of the secondary star, are not confirmed.

The Frequency of Stars of Variable Velocity. R. M. PETRIE, *Dominion Astrophysical Observatory*.—Frequency distributions of probable errors in radial-velocity determinations show, in each sample studied, a sharp rise from zero to

a maximum corresponding to the observational error followed by a slower and irregular decline at higher values. One can deduce from the frequency curves the percentage of stars of variable velocity, assuming that the observational errors are distributed normally. Five homogeneous samples have been investigated as follows: 489 B stars observed at Victoria, with single-prism dispersion; 510 A stars observed at Victoria with single-prism dispersion; 237 G stars, 373 K stars, and 150 M stars, all observed at Mount Hamilton with three-prism dispersion. The percentage of variable velocity stars and the average probable error of one plate are as follows:

Stars	Variable velocity	Probable error
B	49%	± 4.5 km/sec
A	55%	± 1.8 and ± 3.8 km/sec
G	50%	± 0.5 km/sec
K	50%	± 0.5 km/sec
M	59%	± 0.5 km/sec

Thus approximately one-half of the stars measured for radial velocity appear to be variable and are, presumably, mainly double stars.

On the Recession of Stellar Associations from the Galactic Center. PARIS PISMIS, *Tacubaya and Tonantzintla Observatories, Mexico*.—The radial velocities of the stellar associations listed by Morgan *et al.*, are analysed. Of the 27 associations only 23 are considered for which sufficient data on the radial velocities are available (from Wilson's Catalogue). After the effects of the local solar motion and of galactic rotation—the latter with the exact formula and the Camm function—are eliminated, the residuals show a systematic tendency to be negative in the hemisphere towards the galactic center and positive away from the center. It is shown that these residuals can be interpreted as the radial components of an expanding motion of the associations; hence the conclusion, that the spiral arms in the solar neighborhood are receding from the galactic center at the rate of 4 km/sec, with respect to the sun. It is possible that this velocity is the vestige of the rather high expansion velocity that the primeval neutral hydrogen arm may have had, similar to the expansion velocity observed by the Dutch astronomers at 3 km/sec from the galactic center. This work will be published in detail in "Boletín de los Observatorios Tonantzintla y Tacubaya No. 19"

The Profile of Solar Lyman-Alpha. J. D. PURCELL AND R. TOUSEY, *U. S. Naval Research Laboratory*.—During the flight of an Aerobee-HI rocket on July 21, 1959 nine solar exposures were made showing the profile of the Lyman-alpha line of hydrogen. Mean altitudes ranged from 92 to 195 km. The dispersion and resolving power of the spectrograph were 2.6 mm/A and 40 000, respectively. Because the spectrograph was stigmatic and pointing was maintained with considerable accuracy, profiles were obtained for several different regions of the sun. The profile shows significant differences between plage areas, inactive regions, and areas near the limb. The width of the emission line at half-maximum is of the order of 1 Å and the wings extend to at least 1 Å on either side. There is a broad central reversal, with an optical depth of 0.1 to 0.5, producing two maxima, separated by 0.35 to 0.5 Å. The maximum on the long wavelength side is usually but not always the less high. The emission line at half-maximum is usually Doppler shifted about 0.025 Å to short wavelengths but one plage region shows a shift to long wavelengths. In addition there is a deep and narrow absorption which is believed to be produced by neutral hydrogen between the earth and the sun. It is assumed that this core is not appreciably Doppler shifted, and can be used as a wavelength standard. The optical depth at the center is of the order of $\frac{1}{2}$ and the half-width is 0.05 Å, uncorrected for instrumental broadening.

The Spectrum of Venus. E. H. RICHARDSON (introduced by ROBERT M. PETRIE), *Dominion Astrophysical Observatory*.—Spectra of Venus and the moon have been compared from 3150 to 4500 Å and from 4850 to 6400 Å. The spectrograph used was a Littrow grating instrument with a dispersion of 16 Å/mm. The absorption bands reported by Koz'yev at 4120 Å and at 4372 Å are not present on the Victoria plates.

Applications of Interferometry to Astronomy. JAMES B. SAUNDERS (introduced by HARRIET H. MALITSON), *National Bureau of Standards, Washington, D. C.*—An interferometer for measuring the aberrations of telescope objectives of all sizes and types has been developed and tested. It is quite applicable to the testing of astronomical refractors and reflectors in situ, concave mirrors (spherical or aspherical), and camera objectives. To test an astronomical objective the eyepiece of the telescope is replaced with a modified Köster's double image prism and the telescope is directed toward a bright star. Two symmetrically located pairs of coherent light beams emerge from the prism, one of which is received by a camera and the other by the operator's eye for maintaining adjustments of the interference fringes. The width of the fringes may have any chosen value and the contrast in the neighborhood of the zero-order fringe approaches infinity. Due to polarization effects in the prism, two quarter wave plates are used with it for obtaining best contrast in the fringe pattern. Other important applications of this interferometer are: (1) the measurement of the angular separation of binary stars, (2) the study of the turbidity of the atmosphere through which light travels to a telescope, and (3) the automatic control of telescope pointing, in combination with photoelectric cells.

Emission Cores in the Ca II Lines in Plages. ELSKE V. P. SMITH, *Sacramento Peak Observatory*.—Observations of the Ca II H and K lines in plages were undertaken to investigate some of the observed characteristics of the emission cores, specifically (a) the intensities of the emission, H₂ and K₂, (b) the intensities of the central absorption, H₃ and K₃, and (c) the intensities of the H₁ and K₁ absorption, (d) the emission line widths, and (e) the separation of the emission peaks. The behavior of these parameters in the H-line closely parallels those in the K-line. Similarly, there exists a very high correlation between the K₂ and K₃ intensities. A range of a factor three in the emission-line width occurs on the sun between such different features as sunspots on the disk and plages near the limb. The relevance to the Wilson and Bappu (1957) effect will be discussed. The separation of the emission peaks is not uniquely related to the width and, in fact, behaves differently in certain respects. Whereas the emission-line width in plages exceeds that of the neighboring quiet disk, the separation is less in plages than on the normal disk. The separation is inversely proportional to the intensity of either K₃ or K₂. The width behaves in a more complex fashion. We question the validity of using velocity units for either width or separation since the difference between the H and K lines is not consistent with Doppler displacement. The intensity of the K₁ absorption just beyond the emission core depends somewhat on the intensity of the emission, though the variation within a single plage and from plage to plage is very much less. This fact, as well as the center-to-limb variations of their emission profiles, suggests that plages are restricted to a thin layer in the chromosphere with little effect on the temperature structure of the underlying photosphere.

A Search for Possible White Dwarfs in the Coma Berenices Galactic Cluster. C. B. STEPHENSON, *Warner and Swasey Observatory*.—The region of the Coma Berenices galactic cluster has been searched for stars having ultraviolet excesses such as should characterize typical white dwarfs, using Case Schmidt plates and the three-image method first utilized at Tonantzintla. The method has in fact been applied at

Tonantzintla to a blue-star survey partly overlapping the regions included in the present survey, but the results were considered by the Tonantzintla workers to be unsuitable for study of the fine structure of the surface distribution of their blue stars. Moreover, they gave no data for Luyten blue stars in the Coma area beyond noting that some of them do not appear blue on the Tonantzintla plates, while Luyten's stars, which were not considered by him necessarily to be white dwarfs, have been used on occasion to compare predicted numbers of white dwarfs in the Coma cluster with observed numbers. Consequently it was hoped that the new survey would reinforce the Tonantzintla material. Five bright-ultraviolet stars were found within $2\frac{1}{2}^\circ$ of the center of the cluster. Two of these were identified previously at Tonantzintla, two were found by Luyten, and one is new. Fourteen additional such stars, of which six are new, were found in four comparison fields near the cluster. All of the Tonantzintla bright-ultraviolet stars above the magnitude limits of the Case plates were confirmed. The results indicate no pronounced clustering of bright-ultraviolet stars in the direction of the Coma cluster down to photographic magnitude 17.0, which is consistent with the Tonantzintla material. Accordingly, it is concluded that the number of such stars which are members of the Coma cluster is quite uncertain.

Remarks on the Determination of Velocity Gradients in Moving Atmospheres. R. G. TESKE, *Harvard College Observatory*.—Theoretical line profiles and curves of growth have been constructed for atmospheres in uniform and in non-uniform motion; they are based on a pure absorption mechanism in a Milne-Eddington model. The purpose of this study is to describe methods for the detection and measurement of atmospheric velocity gradients such as those which may arise during Cepheid pulsation. The positions of cores of absorption lines which are formed in a uniformly expanding (contracting) atmosphere will be a function of the central intensity of the line; the relation is such that strong lines are less displaced by the effects of expansion than are weak lines. This relative position line strength relation depends upon the velocity of expansion and is further complicated by the smearing effect of the spectrographic apparatus. Thus, if one relates measured radial velocity to a parameter which is proportional to line strength, it is possible to infer the presence of velocity gradients where none in fact exist. An analysis of theoretical absorption lines formed in a velocity-gradient atmosphere shows that the relation between the displacement of the line cores and their mean depth of formation τ , measured in the continuum, does not yield the input velocity field. Recourse is had to high-precision spectrophotometry; a spectrophotometric method is described which allows quantitative determination of differential atmospheric motions independent of radial velocity data. The method is limited to a velocity function that is linear with optical depth in the continuum. Some of the calculations upon which this investigation is based were performed with the IBM 704 computer at the Massachusetts Institute of Technology; others were done with the IBM 704 at the Smithsonian Astrophysical Observatory's Computations and Analysis Division.

The Cluster Membership of Objects Lying above the Main Sequence in NGC 6530. PIK SIN THE AND V. M. BLANCO, *Case Institute of Technology*.—NGC 6530 according to Walker (1957) shows a normal main sequence up to visual magnitude 12.0. Fainter stars, presumably contracting objects, fall above the zero-age main sequence as defined by the brighter stars. However, Wallenquist (1940) has found that these faint stars show no clustering, which suggests that they are field stars. To examine this further, colors and magnitudes within 1° of the cluster were determined photographically for 3000 stars. Walker's sequence and one in NGC 6531 were used. Two or three plates were used in each magnitude determination. The probable error of a magnitude is 0.12, which although high does not affect our conclusions.

Checks for systematic errors show these to be negligible. The stars were divided into five groups located in areas near NGC 6530 showing strong absorption and in a nearby clear region. In all cases the diagrams show stars above the main sequence. The numbers of such stars observed/unit area are comparable with Walker's. The surface distributions of stars of different magnitudes near NGC 6530 show a definite clustering only for stars brighter than 12.5, in agreement with Wallenquist's results. Wolf diagrams constructed from the magnitude distributions in the dark cloud that forms a backdrop to M 8 and in a nearby clear region gave an estimate for the cloud's distance of 1.3 kpc. The total absorption of the dark cloud is 1.7 magnitudes. This is sufficiently low to permit the observation of background stars in appreciable numbers. The number of such stars expected to fall above the NGC 6530 main sequence is in rough agreement with observations. It appears from this study that in the case of NGC 6530 at least the majority of Walker's stars are highly reddened background stars of early type.

The 600-Foot Radio Telescope. J. H. TREXLER (introduced by E. Stuart Ferguson), *U.S. Naval Research Laboratory*.—The U.S. Navy is building for the department of Defense and the scientific community, a 600-ft radio telescope at Sugar Grove, West Virginia. When completed in 1962, it will be a significant new tool for astronomical observations at meter and decimeter wavelengths. The radio optics of the instrument will consist of a 600-ft-diam parabolic mirror with a prime focus observing station 240 ft above the surface. The geometry of the optics is maintained through changing environments by a multiplicity of closed loop servo mechanisms which continually refigure the mirror and adjust the focus. The radio optics of the telescope are mounted in an altitude-azimuth configuration providing access to the entire sky. Tracking rates are sufficient to follow celestial objects at distances beyond one earth radius. The 2.6×10^4 m² collecting area of the telescope, effective at wavelengths of low absorption, will provide promising approaches to intergalactic studies as well as more problems. In addition to the classical technique of passive observation, the new field of radar astronomy will be provided with a versatile and powerful tool.

The Extragalactic Distance Scale. SIDNEY VAN DEN BERGH, *David Dunlap Observatory*.—Luminosity classification techniques have been applied to five members of the local group for which distances have recently been given by Sandage. The LMC and SMC were classified on prints kindly made available by Dr. de Vaucouleurs. The absolute magnitude calibration for each luminosity class was obtained from the red shifts and apparent magnitudes of field nebulae by assuming a Hubble constant of 100 km/sec/Mpc. After correcting for the fact that field nebulae were selected for radial velocity observation by apparent magnitude, one obtains the distance moduli given as follows:

Name	Type and class	m-M (DDO)	m-M (Sandage)
M31	Sb I-II	24.1	24.6
M33	Sc II-III	24.9	24.5
LMC	Ir/Sbc III-IV	18.6	19.2
SMC	Ir IV/IV-V	19.0	19.2
NGC 6822	Ir IV-V	25.0	24.1

Comparison of Sandage's distance moduli with the DDO distance moduli gives

$$H = 100^{+20}_{-17} \text{ (me) km/sec/Mpc.}$$

(The mean error takes into account the uncertainty in the correction for selection effects.) Two assumptions are involved in this determination of the Hubble constant. (1) The galactic absorption is given by $A_{zp} = 0.24 \text{ cosec } |b|$. (2) The distances of local group members are those given by Sandage, which are essentially based on the luminosity calibration of novae by T. Schmidt.

Recent observations of globular clusters in M31 by Kron and Mayall and the revision of the absolute magnitudes of RR Lyrae stars by Eggen, Hoyle, and Sandage suggest that Sandage's distance moduli for members of the local group are possibly too large. If this is the case then the Hubble constant is probably slightly larger than 100 km/sec/Mpc.

Transition Probabilities and Collisional Cross Sections for Ultraviolet Lines. CARLOS M. VARSANSKY, *Department of Physics, University of Colorado*.—With the advent of rocket-born and satellite-born spectrographs it is becoming possible to study celestial objects in the hitherto inaccessible ultraviolet. The spectroscopic analysis will require the knowledge of the basic atomic parameters of the lines observed. To satisfy this need, a program for the computation of these parameters has been started at the University of Colorado. The nuclear-charge expansion method of Layzer and Varsavsky has been applied to the computation of the electric dipole matrix elements for many lines of interest. The method is particularly suitable for the treatment of a particular transition along an isoelectronic sequence. In a forthcoming publication we shall present the numerical results obtained for typical allowed transitions in the isoelectronic sequences from helium through chlorine (except neon), together with a detailed account of the mechanics of the method that will enable other investigators to calculate the matrix elements for any other transition of interest. The matrix elements for electric dipole transitions are easily related to optical transition probabilities and total excitation cross sections by electronic impact. In the first case we must make some assumptions about the coupling of the angular momenta. Our tables are based on the L-S coupling scheme. In the case of total cross sections, a simple relationship is obtained if we can make use of the Born approximation, and if the transition is optically allowed; these restrictions reduce, of course, the scope of the tables but allow the treatment of many transitions of interest in the solar corona. An attempt is made to evaluate our method by comparison with the available experimental and theoretical data. In the few cases where such data exist the agreement is satisfactory.

The Variable K Line of 73 Draconis. WILLIAM H. WEHLAU, *University of Western Ontario*.—Six spectrograms from the Dominion Astrophysical Observatory at 4.5 Å/mm are being used to study the variable spectrum of 73 Draconis. The *H*II, *H*II, and *T*II lines vary in phase. At *H*II minimum, the *Ca* II line at 3933Å is sharp and weak (equivalent width about 0.2Å) for the spectral type, A2p. At *H*II maximum a broad, shallow *Ca* II line is present. It is about 5 Å wide at half-intensity, with a central depth of about 0.3. This broad line appears to vary in phase with the other variable lines mentioned; all of them show a longer minimum than maximum intensity. If a correction for a depression of the continuum by the broad K line is applied, the equivalent width of the sharp component remains constant during the period of spectrum variability.

An Infrared Survey of the Magellanic Clouds. I. Four Regions in the Large Cloud. B. WESTERLUND, *Uppsala Southern Station, Mt. Stromlo Observatory*.—Infrared magnitudes and red minus infrared color indices have been measured for 303 stars in four regions of the Large Magellanic Cloud. The regions are: A, the surroundings of 30 Doradus; B, the Bar; C, the region between 30 Doradus and Shapley's Constellation III; and D, Constellation III. Two hundred and twenty-five stars have been classified as MO or later in the Case system; 9 stars appear to have an intensity distribution similar to that of carbon stars. Thirty red variables have been found. The infrared absolute magnitudes are found to be -8.2 mag for supergiants of class M1 and -8.6 mag for those of class M2 using a distance modulus of 19.0 mag for the Large Cloud. The corresponding intrinsic colors are $(R-I)_0 = +1.13$ mag and $+1.33$ mag, respectively. The infrared absolute magni-

tudes of the giants of classes M4–M6.5 in the Bar appear to be somewhat brighter than -6 mag. The standard deviations of the individual values are ± 0.5 mag for the absolute magnitudes of the supergiants and ± 0.13 mag for their colors. The M supergiants are most numerous in the region of 30 Doradus but exist in all four areas. They are often situated in or near groups of blue stars but they avoid the regions richest in gas. Interstellar dust has been found in parts of the 30 Doradus region, Constellation III, and the Bar. The maximum absorption measured amounts to $A_v \sim 1$ mag. The luminosity of the late M stars in the Bar appears to place these stars among the red giants of population II. Eight of the nine possible carbon stars have been found in the Bar. Their mean infrared absolute magnitude is -5.7 mag. Confirmation of the classes of these stars is most desirable. The survey is being carried out on plates taken with the 20/26-in. Schmidt telescope at Uppsala Southern Station.

Theoretical Study of the Solar Lyman-Alpha Profile. K. G. WIDING AND D. C. MORTON, *U. S. Naval Research Laboratory, Washington, D.C.*—An attempt is made to find a theoretical profile of the solar Lyman-alpha line to account for the one observed with a rocket-borne spectrograph by J. D. Purcell and R. Tousey on July 21, 1959. The emission line and the shallow central reversal are assumed to be formed in the chromosphere, while the deep central absorption is supposed to be formed outside the sun. The analysis is based on the chromospheric theories of Jeffries and Thomas which combine solutions of the statistical equilibrium equation and the transfer equation, without requiring thermodynamic equilibrium. It is assumed that the absorption coefficient has a Doppler profile and that the line is formed by completely noncoherent scattering. As a first approximation, the region of line formation is taken to be isothermal. The depth of the central reversal and the width between the maxima are reproduced by an electron temperature of 1.3×10^5 K and a total number of ground-state hydrogen atoms of 3×10^{14} cm $^{-2}$. However the predicted wings drop much more steeply than the observed ones. For an electron density of 10^{10} cm $^{-3}$ the predicted central intensity is 4.4×10^{-8} erg sec $^{-1}$ cm $^{-2}$ sr $^{-1}$ cps $^{-1}$ which agrees with the value of 3×10^{-8} deduced from the observed profile and measurements of the total Lyman-alpha intensity made during the flight. For a second approximation we represent the Planck function by

$$B_\nu(T_e) = S_1(1 + Ae^{-c\tau_0}),$$

where τ_0 is the optical depth at the center of the line. We neglect the radiative-excitation term relative to the collisional-excitation term. A profile with a central reversal similar to the observed one is obtained for a c of 0.15 and any A between 10^4 and 10^{10} . The profile differs little from the one given by the isothermal model, and again the predicted wings drop far too steeply. The central intensity, for an electron density of 10^{10} cm $^{-3}$, is 2.1×10^{-7} erg sec $^{-1}$ cm $^{-2}$ sr $^{-1}$ cps $^{-1}$, too large by an order of magnitude. Lowering the electron density to 10^9 cm $^{-3}$ will give agreement with the observations.

On the Evolution of Close Binary Systems. FRANK BRADSHAW WOOD, *Flower and Cook Observatory, University of Pennsylvania*.—Three problems in the study of close binaries are large ranges in mass ratios, many departures from the mass-luminosity relation, and the fact that when one component fills the Jacobian limiting surface, this is usually the less massive component. Efforts to explain these by large scale mass transfer have not shown how this can be done without disturbing the equilibrium. A protostar with two condensation centers will become a binary. Recent work on the evolution of single stars suggests that the contraction centers probably have a higher initial condensation of dust to gas than the medium from which they are condensing, and later will attract the gas which comprises most of the star. In the case of a close binary, these centers will compete for the gas (chiefly hydrogen) in the medium from which the stars form. If one center

is more massive than the other, its contraction stages will take place more rapidly. At the time this component reaches the main sequence, the less massive component will not be able to retain the material lying outside the Jacobian limiting surface, and this must be acquired by the other component or be lost to the system. Qualitatively this concept offers a possible answer to the problems cited. The mass ratios may become large because much of the original mass was either lost or acquired by the more massive star. The secondary component will be hydrogen-poor, and hence will have a higher central temperature than normal for its mass and the composition of the original mixture; thus its departure from mass luminosity would always be in the same direction. If the heavier component also loses mass it will be overluminous for the same reason; if it does not, it will be normal; if it acquires much of the hydrogen which otherwise would have gone to the secondary, it will be underluminous. These cases all exist. Finally, the less massive components will be found at the limiting boundary surfaces, not because of normal evolution, but because the matter beyond this limit was lost to the other component or to the entire system.

Temperature Determinations for Nuclei of Thirteen Planetary Nebulae. H. ZANSTRA AND L. H. ALLER, *The University of Michigan Observatory*.—The temperature determinations presented are based on calibrated slitless spectrograms showing monochromatic images as well as the continuous spectrum of the central stars. Since relative intensities of the emission lines were available, only the A_ν value of one of the monochromatic images as compared with the adjoining star spectrum was required in addition to the electron temperature which plays a minor part. Also the influence of interstellar reddening is of minor importance. The stellar temperatures obtained were T_H from the recombination of hydrogen, T_{ee} from the electron energy exciting the forbidden lines, and T_{HeII} from the HeII recombination spectrum, the star being formally treated as a blackbody and the absorption of ionizing quanta being considered complete. With one exception,

the six nebulae having no observable HeII, all yield $T_H > T_{ee}$. If the absorption of ionizing quanta were incomplete, one should have $T_H < T_{ee}$. We may conclude, therefore, that the combination of a blackbody energy distribution with complete absorption is sufficient to explain the H absorption region. Literally speaking, the absorption would be more than complete. The seven nebulae showing HeII all yield $T_{HeII} \gg T_H$ and moreover, with one exception, $T_H < T_{ee}$. The latter fact may be understood by the Lyman-alpha line of HeII giving additional ionization of the hydrogen with large photo-electron energies. As a model one might tentatively adopt a temperature T_H for the wavelength region $\lambda > 228$, and a much higher temperature $T_{HeII(H)}$ for the region $\lambda < 228$, so there appears to be an ultraviolet excess produced by some unidentified mechanism. The stellar temperatures T_{HeI} from recombination of helium were about 4000° higher than T_H , on the average. A similar discrepancy is indicated by the spectral energy distribution of the corresponding far ultraviolet regions $\lambda < 509$ and $\lambda < 912$ from model stellar atmospheres of O stars.

The Energy Equilibrium of the Solar Chromosphere. J. B. ZIRKER, *Sacramento Peak Observatory*.—Athay and Thomas (1956) investigated theoretically the temperature structure of the solar chromosphere permitted by the requirements of energy equilibrium. They were able to apply their results in either of two extremes: either (a) under conditions of very high local opacity, when the net emission at the wavelength in question is zero, or (b) under conditions of very low local opacity when self-absorption can be neglected. Methods for the treatment of situations intermediate to these extremes have been developed since 1956. This paper presents one formulation of these methods and applies them to the solar chromosphere. Stable temperature intervals emerge below $10\,000^\circ\text{K}$ and around $60\,000^\circ\text{K}$ based, respectively, on hydrogen and ionized helium emission. The interval between $15\,000^\circ\text{K}$ and $40\,000^\circ\text{K}$ appears to be unstable.

NEW BOOKS RECEIVED

- Himmelsmechanik, Band 1.* by Karl Stumpff, published by Deutscher Verlag der Wissenschaften, Berlin 1959. Price DM 56.80.
- The Structure and Evolution of the Universe*, by G. L. Whitrow, published by Harper and Brothers, N. Y. \$1.45.
- Second Conference on Coordination of Galactic Research, I. A. U. S. No. 7*, A. Blaauw, editor, published by Cambridge University Press, New York. Price \$3.00.
- Astronomischer Jahresbericht, Band 57, Die Literatur des Jahres 1957*, Astron. Rechen-Inst. in Heidelberg, published by Walter de Gruyter and Co., Berlin. Price DM 60.
- Recent Advances in Atmospheric Electricity*, Proc. 2nd Conf. on Atmospheric Electricity, L. G. Smith, editor, published by Pergamon Press, Inc., New York. Price \$17.50.
- Electromagnetic Phenomena in Cosmical Physics, I.A.U. Symposium No. 6*, B. Lehnert, editor, published by Cambridge University Press, New York. Price \$10.00.
- Magneto-Ionic Theory and Its Application to the Ionosphere*, by J. A. Ratcliffe, published by Cambridge University Press, New York. Price \$7.50.
- The Theory of Space Time and Gravitation*, by V. Fock, translated from the Russian by N. Kemmer, published by Pergamon Press, New York. Price \$15.00.

A Study of Visual Binaries Having Primaries Above the Main Sequence*

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New MK spectral types determined by the writer are presented for both components of more than 100 visual binaries having primaries above the main sequence. MK types are also given for one or more components of 40 other systems, some of which are optical pairs. New photometric observations are given for a number of systems for which previous data needed improvement.

This material is used, with previously available data of the same sort for additional visual binaries having off-main sequence primaries, for a discussion of a number of problems. The following conclusions are reached: (1) Between A0 and M2 and up to luminosity class II, visual binaries indicate that only luminosity class II needs an appreciable change in the absolute magnitudes assigned by Miss Roman (1952), or Keenan and Morgan (1951); (2) With few exceptions, classification of normal stars by visual

comparison of slit spectrograms with standard spectra yields spectral types for which the uncertainty in the associated absolute magnitudes does not vary much with position in the H-R diagram from the main sequence to luminosity class II; (3) The H-R diagram for the components of visual binaries is consistent with current views of the general trends in stellar evolution; (4) Hypothetical parallaxes of the wider visual binaries are not useful for mass estimations because of the influence of selection effects; (5) The space motions of the binaries of the present study are mainly small, and are nearly independent of the spectral type of the stars involved; and (6) The physical nature of the stars occurring in visual binaries is nearly independent of the separation of the components.

I. INTRODUCTION

VISUAL binaries having primaries above the main sequence are of interest because of their bearing on the problem of stellar evolution and because of the fundamental information that they may afford about stars above the main sequence.

With few exceptions, the pairs discussed are situated north of declination -30° . Those for which new data are presented are almost always such that the spectrum of each component could be recorded in usable quality by means of the 36-in. refractor of the Lick Observatory, with which the writer obtained all the new spectrograms. The visual difference in magnitude, Δm , between the components of systems for which this published datum was of low precision was measured visually [Sec. III(a)], and a few magnitudes were measured photoelectrically [Sec. III(b)]. With respect to the systems of the sort considered, this survey is as complete as practicable with the aid of published information and Lick instrumentation.

II. OBSERVING PROGRAM AND INSTRUMENTATION

The importance of selection effects in much of the discussion to follow warrants consideration in some detail of the process by which a double star was chosen for observation in this program.

An extensive list of visual binaries for which either component was known or suspected to lie above the main sequence was made available to me by Dr. W. P. Bidelman. Although, in fact, the list included only systems for which it was probable or certain that at least the primary lay above the main sequence, this choice was not deliberate. Published spectral types, chiefly on the Mount Wilson system and usually pertaining to the

primary star alone, were available for some stars. However, for most systems the conclusion that the primary was above the main sequence rested on such bases as dynamical parallaxes, *Henry Draper Catalogue* types, and proper motions of stars contained in the H-R diagram. Proper motions were also the basis for adding a few stars having spectral types determined by Vyssotskiy (Hill and Schilt 1952).

Except for occasional pairs of unusual interest, a double star was put on the observing program only if it seemed rather certain that it was a physical system. All of these systems have very long periods of revolution—the majority of the projected separations are between 1000 and 10 000 a.u.—so the relative motions are small or unobservable. Thus there was no possibility of concluding that a system was physical because of curvature in the relative motion. Instead, the criterion of a physical system was principally common proper motion; in dubious cases, common radial velocity was demanded, and the system was then rejected if this information was unavailable. The requirement of common proper motion resulted in only a slight tendency for the systems observed to show increasing tangential velocity with increasing distance from the sun. About 90% of the stars of this survey are within one kiloparsec of the sun.

The spectrograms used for spectral classification were obtained with the one-prism, 6-in. camera combination of the 36-in. refractor, with the plates having, generally, baked Kodak IIa-O emulsion. This equipment yields a dispersion of about 150 Å/mm at the focal plane, which appears to be adequate for the assignment of reliable luminosity classes for all stars except A-type and early B-type stars. The separation of subgiants from dwarfs may not have been completely successful for these early types. Nevertheless, no appreciable loss in resolution in terms of position in the H-R diagram

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appears to have occurred for these types, as will be indicated in Sec. VII.

Stars fainter than photographic magnitude 11.0 to 1.5 were not observed, nor could uncontaminated spectra of both components be obtained for a double star for which the separation projected on the normal to the spectrograph slit was smaller than two seconds of arc. The width of the slit was about $1\frac{1}{2}''$. The limiting practical Δm , as a function of normal-to-slit separation, ranged from about 1 mag at $2''$ to about 5 mag at $10''$, for good seeing.

For nearly one-third of the pairs observed, the separation of the components of a double star perpendicular to the spectrograph slit was increased by turning the slit out of the normal east-west position.

It is obviously impossible to give a simple description of the degree of completeness of the new observations. Suffice it to say that, of the stars considered by the writer to be likely candidates for membership in the class of objects to be studied, all systems were observed for which it seemed probable that successful observations would be possible. This procedure resulted neither in a completeness within a given volume of space nor to a given apparent magnitude. For example, of the northern probable giant-primary systems brighter than apparent magnitude 6.5 in Bidelman's unpublished compilation, only one-third now have reliable spectral types for both components.

III. PHOTOMETRY

(a) *The magnitude differences.* The values of Δm were taken from published data wherever it seemed likely that their precision was adequate for the purposes at hand. Preference was given to the values published by Wallenquist (1954) and, for the wider pairs, to individual determinations of the magnitudes of the components [see references in Sec. III(b)]:

For about one-third of the pairs observed spectroscopically, the only published values of Δm are the direct visual estimates of double star observers, such as were given by Aitken (1932) for all of the stars of his *General Catalogue*. For the brighter stars these estimates have been compiled and reduced by Öpik (1924). For pairs in this group wider than $4''$ or $5''$, the writer used the photographic magnitude differences in the *Astrographic Catalogue*. These were considered as International photographic magnitudes and were converted into visual Δm with the aid of mean color indices as a function of spectral type and luminosity. The resulting Δm was usually averaged with that given by Aitken or Öpik. A comparison for selected pairs of these astrophotographically-deduced Δm 's with those given by Wallenquist indicated that the astrographic values are about as reliable for the wider pairs (none exist for close pairs) as are the ADS and Öpik data. A comparison of results from these sources with those from Wallenquist for the pairs wider than $4''$ to $5''$ suggests a mean error

of about ± 0.2 mag for $\Delta m \leq 3$ mag with a lower precision for still larger Δm . No difference in precision between different zones of the *Astrographic Catalogue* appeared large enough to warrant assignment of different relative weights.

Closer pairs lacking a reliably determined Δm were observed by the writer, who in almost all cases used the Lick 12-in. refractor. These observations were made visually with a double-image micrometer of P. Muller's design (Muller 1948), equipped with a suitable polaroid analyzer and used in the manner described by him. An upper limit exists to the separation of a double star whose Δm can be measured reliably with this instrument. This limit was about $6''$ for the 12-in. telescope, and $2''$ for the 36-in.; hence most of the measures were made with the 12-in. Each pair was measured on two nights. The internal mean error of such a Δm determination appeared seldom to exceed ± 0.05 mag. The possibility of larger systematic errors, however, accounts for omission of the formal, internal errors of the results that are in Tables I-IV. There the measured values of Δm , which are equal to the assigned differences in absolute magnitude for the binary components for which the writer is indicated as being responsible for the Δm , are given to the nearest tenth of a magnitude, to which degree of precision they should be reliable.

The possibility of appreciable systematic errors in the writer's measured Δm was tested by measuring several pairs for which Wallenquist has published values to which he accords high weight. These observations indicated no error dependent upon magnitude difference, and probably no substantial error dependent upon color. The polaroid itself is neutral in the visual region of the spectrum, within the tolerances of visual photometry.

(b) *The apparent magnitudes.* Since the absolute magnitude calibration utilized for the MK spectral types is based on the Harvard visual magnitude system, this system was adopted for the present study. Except for six pairs for which visual magnitudes were determined photoelectrically, the apparent magnitudes were taken from various sources, as follows:

For stars brighter than magnitude 6.5, the magnitudes were taken from the *Yale Catalogue of Bright Stars*, whose magnitudes are those of the *Revised Harvard Photometry* (Pickering 1908), which defines the Harvard visual system. We shall refer to these magnitudes as HR magnitudes. Besides the HR magnitudes, equal preference in the case of bright stars, and first preference for fainter ones, was given to published photoelectric values of V in the (B, V) system of Johnson and Morgan (1953) or in the (P, V) system of Kron and Smith (1951). These visual photoelectric magnitudes were converted to Harvard visual magnitudes by the approximation,

$$m_v = V + 0.07 + 0.1(B - V), \quad (1)$$

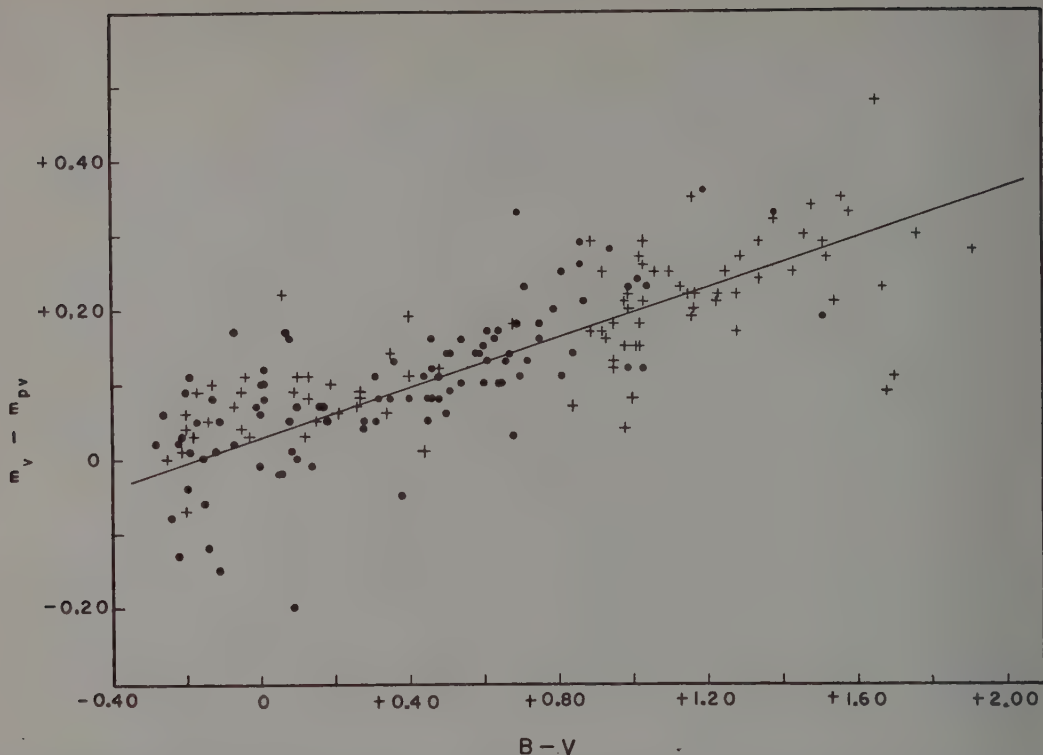


FIG. 1. The relation between Harvard photovisual and Harvard visual magnitudes. Dots: stars of luminosity class IV and fainter; crosses: classes I to III-IV.

suggested by a comparison of Johnson's magnitudes and color indices with HR magnitudes for the same stars. Unpublished data in the (B, V) system for a few stars of the present study were also kindly communicated to the writer by Mr. G. A. Bakos, of the David Dunlap Observatory.

After the sources mentioned, preference was given to visual magnitudes derived from Mrs. Payne-Gaposchkin's (1938) compilation of Harvard photovisual magnitudes. This system was related to the system of the *Revised Harvard Photometry* by comparing the photovisual magnitude, m_{pv} , with the HR magnitude, m_v , for stars for which accurate color indices had been published. These color indices were taken from data by Johnson and Morgan (1953) or from the six-color papers (Stebbins and Whitford 1945; Stebbins and Kron 1956). A comparison based on 201 stars is shown in Fig. 1, in which the straight line,

$$m_v = m_{pv} + 0.026 + 0.168(B - V) \pm 0.005 \pm 0.006 \quad (\text{pe}), \quad (2)$$

is the result of a least-squares solution. Only stars having published MK spectral types were used in the comparison. There is no obvious difference between the determination given by different luminosity classes, but the relation is not quite linear for the bluest stars.

Mean color indices as a function of spectral type and luminosity were applied to the photographic magnitudes of the AGK₂ (Schorr and Kohlschütter 1951-54), of Schilt (Hill and Schilt 1952; Barney 1953, 1954), and of the Bergedorf Selected Areas (Schwassman and Van Rhijn 1935-53), to derive visual magnitudes of many stars for which no other magnitudes were available.

The sources of magnitudes described above did not suffice to yield apparent magnitudes for all the stars that were observed in the present study. For these remaining objects only the one-decimal magnitudes of the *Henry Draper Catalogue* were available. In view of the large uncertainty in these magnitudes, those for stars possessing only corrected BD values were derived photoelectrically with the 12-in. telescope for pairs whose eventual inclusion in the calculation of masses was contemplated. Magnitude data for convenient standard stars were kindly furnished by Dr. G. E. Kron. The resulting magnitudes are scattered through Tables I-IV, rounded to 0.1 mag, to which figure they should be entirely reliable.

Except for the AGK₂, the sources that were consulted for magnitudes frequently take no cognizance of the fact that a star is double. Hence, for the wider pairs, it is often impossible to be sure whether the magnitudes refer to component A or to the combined

light of AB. The writer adopted conventions based on a comparison of the various sources with the meticulous AGK₂ (cf. Pickering 1912), but the decisions were occasionally uncertain.

In regard to the present lists, Tables I–V, it may be supposed—possibly erroneously in some cases—that the data tabulated are uncontaminated by objects lying more than 2" from the positions defined by the brightest objects responsible for entries in the respective catalogues.

IV. SUMMARY OF THE OBSERVATIONS

Following the example of Bidelman (1958), we have summarized the data according to the spectral type of the secondary. In the case of dwarf companions, this arrangement presumably yields a segregation of systems according to upper limit of the age of a system, but this interpretation may not be valid in the case of systems whose secondaries are off the main sequence.

The systems listed in Tables I–IV were observed either spectroscopically or photometrically by the writer, except for a few pairs not included in Bidelman's paper for which data have been published by other investigators and which were included in some of the computations to follow. A description of Tables I–IV follows.

Column 1. Number of the system in the Aitken (ADS) or Burnham (BDS) double star catalogue. Daggers (†) indicate systems discussed by Bidelman (1958) and included here in order to present new observations, usually photometric ones. The components of a double star are always A and B, in the nomenclature of the appropriate double-star catalogue, if there are two components with no other comment. More than two components without comment indicates A, B, C, etc., in that order. All other cases are identified specifically (cf. ADS 11834, Table I). In case of confusion or error, the magnitudes and separations should permit unambiguous identification.

Column 2. Other designations, in the order of preference, are; Bayer letter, Flamsteed number, HR number, HD number, and BD number. HD numbers stand without other identification, except where necessary to avoid confusion. When only one number is quoted, the familiar ambiguity may exist as to whether component A or AB was entered in the original catalogue.

Column 3. The space velocity of the system, referred to a centroid relative to which the sun has a motion of 20.0 km/sec toward $\alpha_{1900} = 18^h04^m$, $\delta_{1900} = +28^\circ00'$. These are based on the radial velocities in the *General Catalogue* of Wilson (1953), proper motions taken from the sources listed in column 4, and distance moduli resulting from the present material. Interstellar absorption corrections will be discussed later. The absence of an entry in column 3 indicates that no radial velocity determination is known. The larger tangential velocities for systems without radial velocity determinations were also reduced to the local centroid. These reduced tangential velocities, designated by S, are listed in parentheses in column 3.

Column 4. Source of the proper motion, μ , for the systems for which some sort of velocity is presented. The abbreviations are as follows: G, the Boss *General Catalogue* (Boss 1937); Y, the Yale *Catalogue of Astronomische Gesellschaft Stars*, re-observed by photography; E, the Bergedorf *Eigenbewegungs-Lexicon* (Schorr, Kruse, and Imgart 1936); GA, the Greenwich *Astrographic Catalogue* (Dyson 1921, 1929, 1932).

Column 5. The projected separation of the components in astronomical units, usually to two significant figures and based on apparent separations usually rounded to 1".

Column 6. The apparent visual magnitude of the primary on the Harvard system, and the source from which this was obtained. In many cases the known Δm has been used to derive the magnitude of A from the combined magnitude of a system. Abbreviations used here are summarized in the following table.

Abbreviation	Source	Type of magnitude, and reduction to visual
HR	Yale <i>Catalogue of Bright Stars</i> (1940)	Visual
H	Payne-Gaposchkin (1938)	Harvard photovisual; Eq. (2).
Ag	AGK ₂ (Schorr and Kohlschütter 1951–54)	Photographic; Sec. III(b)
C	Columbia Publications (Hill and Schilt 1952)	Photographic; Sec. III(b)
Be	Bergedorf <i>Spektral-Durchmusterung</i> (Schwassman and Van Rhijn 1935–53).	Photographic; Sec. III(b)
J ₁ , J ₂	H. L. Johnson (1953, 1952)	Photoelectric V; Eq. (1)
R	Roman (1955)	Photoelectric V; Eq. (1)
EMS	Evans, Menzies, and Stoy (1957)	Photoelectric V; Eq. (1)
Ba	Bakos (private communication)	Photoelectric V; Eq. (1)
B	<i>Henry Draper Catalogue</i>	Visual
S	Stephenson, photoelectric	Visual

Column 7. The source from which the Δm was obtained. Abbreviations in addition to those already mentioned are tabulated below:

Abbreviation	Source	Type of Δm
W, W'	Wallenquist (1954, 1958)	Visual
A	Aitken (1932)	Visual
O	Öpic (1924)	Visual
S	Stephenson	Visual
As	<i>Astrographic Catalogue</i>	Photographic
Hde	<i>Henry Draper Extension</i>	Photographic

Columns 8 and 9. Spectral types of primary and secondary components, on the MK system. References to published sources are given, as follows: (1) Stebbins and Kron (1956); (2) Bidelman (1954); (3) Bidelman (1958); (4) Roman (1952); (5) Halliday (1955); (6) Bidelman (1956); (7) Roman (1955); (8) Evans, Menzies, and Stoy (1957); (9) Joy (1941); (10) Johnson and Morgan (1953); (11) Bidelman (1951). These references are also applicable to Table V. In some cases the writer re-observed primaries already having published spectral types. When his classification was identical with the published type, an asterisk (*) accompanies the reference. When the type was different, the one given here is the new one, and no reference is made to the published type that differs from it; such cases were rare. Stars that have been announced to be single-line spectroscopic binaries are indicated by the symbol ($\dagger$). A minus sign (—) following a luminosity class indicates slightly higher luminosity than that of the class in question.

Columns 10 and 11. The visual absolute magnitudes. These are based on the luminosity calibration carried out below in Sec. VI, and have been adjusted so that the difference between the absolute magnitudes of A and B equals the observed Δm . In most cases this adjustment was made by altering the preliminary absolute magnitudes by equal and opposite amounts. In a few cases, for which the calculation of luminosity dispersions indicated considerably different dispersions for

the two types of object, the components were altered by unequal amounts.

Column 12. References to remarks, usually concerning the spectra, at the end of each table.

For the calculation of space motions and masses, it was necessary to estimate interstellar absorption corrections to the apparent distance moduli. For apparent moduli smaller than 8.5 mag, the visual absorption was estimated on the basis of a mean value of 0.8 mag/kpc, except that stars more than 100 parsecs from the galactic plane were corrected only for a uniform absorption up to the 100-parsec level. For larger moduli, the correction was estimated wherever possible from published color excesses of neighboring O and B stars.

V. DISCUSSION OF THE OBSERVATIONS

(a) *Spectral types, magnitude differences, and space velocities.* Figures 2–5 confirm the remark by Bidelman (1958) that the systems discussed by him were likely to be typical. His account of the general trends exhibited by the data he discussed applies equally to the present material, and need not be repeated here. Thus, the present Fig. 3 confirms his observation that M and late K giants tend not to have secondaries of types A1 to F4. Of the four primaries as late as K2 in Fig. 3, two are brighter than giants and one of these has a companion that is itself far from the main sequence. If we note that the primaries of Fig. 2 all have $M_v < -1$, and that there are nine primaries in Fig. 4 as late as

TABLE I. Binaries having secondaries of types B0–A0.

ADS or (BDS)	Name, HD or BD	Q or (S)	Source of μ	Sep. (a.u.)	Visual mag of A, and its source	Source of Δm	sp A	sp B	$M_v A$	$M_v B$	Notes
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1630	γ Andr 48640/	21	G	690	2.3, HR	W	K3 II*	A0 p	–2.0	+1.1	a
5409	263084	107	Y	23000	7.2, H	A, As, Hde	K2–3 Ib	A0 V:	–4.1	–0.4	
11834 AC	HR 7140/ HD 175634	21	G	13600	6.1, HR	AB: A AB–C: A, Ag, As	G5 II–III†	B8 V	–1.6	+0.3	
11916	176486/5	49	Y	7100	7.2, H	W /	K4 II–III	B9.5 V	–1.3	+0.4	b
13473	191897			7600	7.6, C, B	S	G0 Ib	B9.5 IV:	–3.8	–1.4	
7	240304/5	(130)	Y	11000	9.8, Ag	A, Ag, As	K1 II–III	A0 III	–1.3	–0.7	
14864†	HR 8164	9	G	4300	5.8, HR	S	M1ep Ib+B ²	B3 V ²	–5.3	–1.5	

^a The absolute magnitudes result from averaging the dynamical parallax of pair BC with the spectroscopic parallax of A. The type of A was first assigned by Morgan (Stebbins and Kron 1956). With the dispersion used, the secondary considerably resembles A0 III, except for having slightly weakened $\lambda 4481$.

^b A is a $\lambda 4150$ star.

TABLE II. Binaries having secondaries of types A1-F4.

ADS or (BDS)	Name, HD or BD	Q or (S)	Source of μ	Sep. (a.u.)	Visual mag of A, and its source	Source of Δm	sp A	sp B	$M_V A$	$M_V B$	Notes
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
558	55 Psc	20	G	1000	5.6, HR	W	K0 II-III	F 3 V	-0.3	+3.0	
2020	16511			750	7.9, H	S	K0 III	F0 V::	+0.7	+3.0	
2286	18715/16			760	7.0, H	W	G5 IV	A7 IV, V	+2.0	+3.6	a
2850	32 Eri			800	4.9, HR	W	G6 II-III	A1 V	-0.7	+0.7	
3551	31231	(66)	GA	910	9.0, H	A	F3 III	F2 III	+0.4	+1.2	
3954	HR 1771	27	G	400	5.4, HR	S	G7 II-III	A7 IV, V	-0.3	+1.1	
5253	ν^1 CMa	24	G	2300	5.8, HR	HR	G8 III	F3 IV-V:	+0.2	+2.3	b
5826	54542/3			6700	8.6, S	A, As	K2 III	A1 V	+0.2	+1.4	
6157	59933/2	(93)	Y	16000	9.6, B	A, As	K0 II-III	F0 III:	-0.3	+0.6	
6376	63210	22	G	800	6.8, C	W	K0 III	F3 V	+1.1	+3.0	
7311	27 Hya	13	G	AB=12600 BC=350	5.0, HR	AB: HR AC: A, As	G8 III-IV*, F4 V†	K2 V	+1.3, +3.2,	+6.4	
7914	93013	16	G	1100	8.1, Be, C	A, As	K0 III	F3 V:	+0.8	+3.2	
8414	105031	41	G	2400	7.7, H	W, H	G8 III	F0 III	-0.1	+0.8	
9740	HR 5831	13	G	3600	6.3, HR	W	G8 II-III	F3 V	-0.7	+3.2	c
10535	HR 6491	43	G	6300	6.4, Ba	Ba	G5 III	F0 V	-0.2	+3.4	
10715	HR 6592	46	G	2400	6.5, HR	W	K1 III	F4 V	+0.5	+3.5	
10748	161262			5800	8.7, S	A, As	K1 II-III	A2 V	-1.0	+1.4	
10955	164253/2	30	G	8000	7.5, H	W	G8 II-III	A1 V	-0.7	+0.6	
11616	173399	28	G	2400	7.2, H	W	G5 IV	F2 V	+2.3	+3.9	
11685	174022	32	G	2200	7.6, H	S	G8 II	F0 III	-1.5	+0.3	
12259	180660/39	(93)	Y	19000	8.7, B	W	K2 II	A4 II	-2.3	-1.8	d
14027	196197	37	G	6700	7.0, H	W	K1 II-III	F2 IV-V	-0.4	+2.1	
14567	200465	9	G	6600	6.5, H	W	K3 II-III	A1 V	-1.5	+1.2	
15685	210390			5000	8.6, S	W	G8 III	F2 III	-0.1	+0.9	
15729	210885	47	G	1800	7.3, C	S	G8 II	A1 V	-1.6	+0.5	
15753	41 Aqr	42	G	360	5.7, HR	S	K0 III	F2 V	+1.3	+2.8	
15881	212391/2	17	G	870	7.2, H	W, H	G5 III	A2 V†	+0.3	+1.2	
15967	213014	31	G	2000	7.7, H	W	G9 III*	F3 V	+0.9	+2.7	
16730	220512	23	G	1000	6.8, B	W	K2 III	F3 V	+0.8	+3.2	

a The hydrogen lines of A are strong in comparison with those of the MK standard μ Herculis. B has sharp lines at the dispersion used.

b CN may be a bit weak in the spectrum of A.

c The CN features suggest a higher luminosity for A than the one assigned.

d B is V342 Aquilae, an eclipsing variable with a depth of primary minimum of 2.5 mag.

K2 and fainter than $M_V = -1$, it is difficult to avoid the conclusion that the time required to produce late-type giants (*not* supergiants) from main sequence stars is comparable with the time in which any dwarf earlier than middle F-type will move well away from the main sequence. This is further confirmed by Fig. 5, and was pointed out by Bidelman.

It is of interest to note that, of the visual binaries for which spectral types are available for both components, 40% of the primaries off the main sequence have companions that are also off the main sequence. Observational selection has undoubtedly made this percentage too large to be representative of a unit volume of space; nevertheless, this statistic is of interest in view of the assumption often made, in the absence of further information, that companions of giant primaries are main-sequence objects.

The following generalizations are based upon the present material and on that of Bidelman, and are intended to characterize only the relevant stars:

1. No dwarf has a companion well above the main sequence that is fainter than itself, either visually or bolometrically. However, the method of selecting the

stars observed is not well suited to the detection of many such cases.

2. If both components are off the main sequence, except among the subgiants, the secondary is very rarely later in type than the primary. There are only four exceptions. These are ADS 14299, where the difference in spectral type is only that between G9 and K0; ADS 10905, where the Δm is only 0.1 mag; BDS 11107, K1 III and K2 III with $\Delta m = 0.1$ mag; and 95 Herculis, for which the Δm is also only 0.1 mag. The same conclusion holds for bolometric magnitudes with three exceptions: ADS 10905, ADS 14299, and HR 1669. All three of these systems have a small bolometric Δm , and, moreover, the bolometric corrections are quite uncertain for the components of HR 1669.

3. No star off the main sequence fainter than $M_V = -2$ has a dwarf companion earlier than B8, for which $\bar{M}_V = -0.5$. No such star fainter than $M_V = -1$ has a dwarf companion earlier than A1, for which $\bar{M}_V = +0.7$; none fainter than $M_V = +0.2$ is accompanied by a dwarf earlier than A6, for which $\bar{M}_V \approx +2.3$; and no star off the main sequence and fainter than $M_V = +1$ has a dwarf companion earlier than F2, for which $\bar{M}_V \approx +3.2$. In terms of bolometric magnitudes, stars off the

TABLE III. Binaries having secondaries of types F5-G0.

ADS or (BDS)	Name, HD or BD	Q or (S)	Source of μ	Sep. (au)	Visual mag of A, and its source	Source of Δm	sp A	sp B	$M_V A$	$M_V B$	Notes
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
926	6645	39	E	1200	7.6, H	A, As	K2p	F8 V	+2.0	+3.9	a
(770)	HR 426/ HD 8956	41	G	7700	6.4, HR	HR, B, As	K1 III	F8 IV-V	+1.1	+2.7	
1697	6 Tri	46	G	320	5.6, HR	W	G5 III	F5 V	+0.8:	+3.8:	b
1764	14202	(72)	G	95	7.8, C	W, Ag	G0 IV	G0 V	+2.8	+4.2	
1971	ν Cet	33	G	1010	5.0, HR	W	G8 III*	F7 V	-0.6	+4.2	
2008	16480	48	G	2500	7.3, H	W	K2 II-III	F7 IV	-0.9	+1.9	
2237	18384	19	G	1560	7.2, H	A, As	G8 III	F6 V	+0.9	+3.0	
2294†	HR 881	60	G	1000	5.7, HR	S	M1 III.2	F7 IV*	-1.1	+2.6	
4097	31 Ori	17	G	1700	5.0, B	O, As, A	K4 III	F7 V	-0.7	+4.2	
4361	HR 1986			1200	6.5, HR	W	K1 III	G0 IV	+0.2	+3.1	
5706	52145			AB=1800 BC=360	7.8, H	A, Ag, As	K1 III, F8 IV-V	F7 IV-V	+1.1, +2.7, +3.0		
6736	69054			1320	6.6, H	A	K0 III	G0 V	+0.9	+4.2	
6921	HR 3428	20	G	AB=2800 AC=8300 AD=1400	6.4, HR	AB: J ₂ AC, AD: W	K0 III*, Am†	G0 IV-V, F5 V	+0.6, +1.9,	+4.6, +3.5	c
7808†	HR 4122	17	G	440	6.5, HR	S	K5 III*	F6 V.2	+0.6	+2.9	
8327	103047/6			4300	8.1, B	W, B	K0 III-IV	G0 V	+2.2	+2.8	
8413	105028	34	G	1740	7.4, H	A	K0 III	F6 V	+1.1	+4.1	
8470	106365	82	G	3100	7.0, R	R, W	K2 III†	F9 V†	+1.6	+3.5	
8516	107341	20	G	1270	6.7, H	W	K1 III-	F9 V	+1.1	+4.1	
8576	108877	39	G	2500	7.5, H	W	G8 III	F7 IV	-0.1	+2.0	
8934	117846	34	G	950	7.4, H	W	G8 III	F5 IV:	+0.4	+1.4	d
9002	119461	22	G	4700	6.9, H	W'	K2 III	F7 V	+0.7	+3.8	
(6632)	HR 5186/ +39°2679	44	G	6450	5.5, HR	Ag, C	K0 III	F8 V	+0.6	+4.1	
9104	123102/3			2200	8.3, B	A	F0 IV	F5 V	+2.2	+3.2	e
9193	124989			1300	8.9, B	A, As	M6 III	F6 V	+1.7	+3.6	
9751	140164			220	7.4, H	S	F7 IV	F7 V	+2.1	+3.5	
9962	145931			6900	6.1, Ba	Ba	K4 II	F6-8 V	-1.4	+3.4	f
10035	HR 6106/5			330	6.0, EMS, HR	EMS	G0 IV*	G0 IV*	+2.3	+2.9	
10077	148683	24	G	4200	7.6, C	W	G5 III	F5 IV	+0.1	+2.0	
10451	156652	19	G	1400	7.0, H	A, As	M2 III	F7 V	-0.1	+3.5	
10782	HR 6626	14	G	1100	6.6, HR	A, As	K3 III†	F7 V	+0.5	+3.4	g
11773	174897	36	G	1850	6.6, H	W	K1 III-IV	F7 V	+0.9	+4.1	
—	74 Dra/ +80°662	130	G	20000	6.1, HR	Ag	K0 III	F8 V	+0.8	+3.9	
14279	γ Del	31	G	340	4.5, HR	W	K1 IV	F7 V	+2.0	+2.9	h
15431	HR 8364	36	G	2300	6.3, HR	W	K0 III	F7 V	+1.2	+3.3	
16407	217294	89	G	600	8.2, H	W	G8 IV	F8 V	+3.1	+4.1	i
16666	σ^2 Cep	8	G	150	5.0, HR	W	K0 III*	F6 V	+1.1	+3.4	

* Nearly all the lines, and especially $\lambda 4144$, are weak in the spectrum of A in comparison with those of the K2 III standard ϵ Draconis. The ratio $\lambda 4078:\lambda 4063$, as well as the strength of the hydrogen lines, indicates a giant, while the CN features suggest that the star is a subgiant.

† Both components are double-line spectroscopic binaries, according to Harper (1921). Petrie (1950) has derived $\Delta m = 0.6$ for the components of B, and finds them to differ little in spectral type. Harper found the components of A to be similar. The magnitudes in the table refer to the brighter components.

‡ This system is in Praesepe, but has been treated as an ordinary multiple star. A appears to the writer to be a $\lambda 4150$ star. The spectrum of C has been described by Bidelman (1956).

§ A should probably be considered a $\lambda 4150$ star.

¶ A spectrogram of A taken on April 28, 1958, exhibits a fairly strong companion line to $H\gamma$, near $\lambda 4350$.

|| The criteria of type are slightly conflicting in the spectrum of B, and it is possible that the spectrum is composite. The system has not been plotted on any of the diagrams.

|| Most of the lines in the spectrum of A may be weak; $\lambda 4144$ is conspicuously so.

|| The spectroscopic parallax has been averaged with the trigonometric value given by Miss Jenkins (1952).

|| $\lambda 4132$ and $\lambda 4383$ are unusually strong in the spectrum of A, as $\lambda 4383$ seems to be in the spectrum of B.

main sequence and fainter than the following bolometric magnitudes have no dwarf companions as early as the accompanying spectral types, whose corresponding mean bolometric magnitudes are in parentheses:

M_b	Spectral type
-2.0	A0(-0.3)
0.0	A5(+2.0)
+1.0	A7(+2.5)
+2.0	F2(+3.2)

The foregoing bolometric comparisons, which cannot be of high precision in view of uncertainty in the bolometric corrections, are based on the bolometric corrections tabulated by Allen (1955). The bolometric plots corresponding to Figs. 2 to 5 do not differ sufficiently from those in the H-R plane to warrant inclusion here.

Pairs with small magnitude differences, two of which (ADS 3409 and 3734) were taken from Bidelman's paper, and the remainder from Figs. 2 to 5, are collected in Fig. 6. None of these stars is on the main

TABLE IV. Binaries having secondaries of type later than G0.

ADS or (BDS)	Name, HD or BD	Q or (S)	Source of μ	Sep. (au)	Visual mag of A, and its source	Source of Δm	sp A	sp B	M _v A	M _v B	Notes
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
205	1153			1360	7.8, B	S	K0 III	G8 IV	+0.9	+3.2	
455	HR 134	26	G	760	6.4, HR	A	K0 III†	K0 V	+1.5	+5.5	
486	3165	38	G	3400	6.8, H	W	K4 III	G8 III-IV	-0.7	+1.8	
990	HR 356	39	G	1850	6.4, Ba	Ba	G9 III	G1 V	+0.2	+4.6	
1634	61 Cet	46	G	6500	6.0, HR	A, As	G5 II-III	G5 V	0.0	+4.4	a
1953	15994			1050	8.0, H	S	K1 III	K1 III	+0.7	+0.8	b
2004	16396	21	G	450	7.4, H	S	K2 III	K2 III	+0.5	+1.3	
2014	16410			830	8.2, H	S	K0 II-III	G8 III	-0.7	0.0	
3079†	39 Eri	54	G	420	5.1, HR	W	K2 III	G2 V	+0.8	+4.6	
—	HR 1322/21	43	G	390	6.5, HR	HR	G0 IV	G5 IV	+2.5	+3.1	
3759	33164			575	7.6, H	W	K1 IV	G5 IV	+2.2	+3.6	
3894	HR 1741	69	G	1640	6.3, HR	O, As	G8 II-III	G1 IV-V	-0.2	+3.2	c
5120	258213	53	E	1670	8.9, Be	S	K2 III†	K1 III	+0.5	+1.2	d
5146	HR 2366	12	G	500	6.3, HR	O, As	K2 III	K0 V	+2.2	+5.1	
5816	54244	44	G	2800	8.4, C	A	K3 III	K3 III	+0.1	+0.2	
6711	69438	26	Y	400	7.8, B	A, As	K1 III-IV	G1 V	+2.1	+3.9	
7873	92321	40	G	2500	8.2, C	W	K4 III	K3 III	-0.4	+0.2	
8591	109213	71	G	2100	7.6, H	S	K0 II-III	G9 III	-1.1	+0.8	
8796	114131			460	8.3, H	S	K1 IV	G5 IV	+2.5	+3.2	
8972	118511	5	G	680	7.7, H	A	K0 III	K0 III	+0.8	+0.8	
(6434)	115136/ 115061	16	G	26000	6.6, H	H	K2 III	K2 III	+0.7	+1.1	
(7068)	HR 5573	31	G	8600	5.7, HR	As	K1 III	G5 IV	+0.6	+3.1	
9479	132883			1850	6.8, J ₁	W	K1 IV:	K0 V	+2.6	+6.1	
9675	138232			1500	8.0, H	W	K4 III	K2 III-	-0.3	+1.0	
9696	HR 5829= HD 139777/ 139813	27	G	1100	6.5, HR	W	G0 IV-V	G8 IV-V†	+3.8	+4.6	
10171	150828			830	8.9, S	W	G5 IV	G8 IV	+3.1	+3.2	
10905	163640			1400	7.3, H	W	A0 III	G8 II	-1.5	-1.4	
—	HR 6693/4	40	G	2400	5.3, HR	HR	M2 Ib-II	G8 II	-3.3	-1.6	e
10993	95 Her	17	G	550	5.1, HR	W	A7 III	G5 III	+0.2	+0.3	f
11318	169392			480	7.6, H	W	G0 IV	G2 V	+3.0	+4.3	
11901	HR 7191	24	G	940	6.5, HR	W	G5 IV	G8 V	+2.8	+5.7	
—	HR 7448/ HD 184902	14	G	16500	6.4, HR	H	K4 III	K0 III	-0.5	+1.1	g
(9851)	HR 7662	40	G	1000	6.1, HR	O, As	K3 II-III	G8 IV:	-0.7	+3.0	
14299	198063	9	G	3500	7.1, H	A, As	G9 III	K0 III	+0.2	+0.9	
14359	198569			1000	8.6, S	W	K1 III	K0 III	+0.8	+0.9	
—	HR 8042/ -43°14327			3300	6.8, EMS	EMS	G3 IV ^a	K0 IV ^a	+3.0	+3.3	
14889	HR 8166	17	G	150	7.0, HR	W	G8 IV-	G5 IV	+2.6	+3.0	
(11107)	205741/76	28	G	30000	7.0, H	H	K1 III	K2 III	+0.8	+0.9	
16228	HR 8654	28	G	700	6.2, HR	S	K5 III	K2 III	-0.9	+1.6	
16317	HR 8696	37	G	200	6.4, HR	W	G8 III-IV	G2 IV	+1.5	+2.7	
16579	218928			900	7.7, H	S	K0 III	K0 III	+0.8	+0.8	
16672	94 Aqr	16	G	280	5.3, HR	W	G5 IV-V†	K2 V	+3.6	+5.8	

^a The hydrogen lines of the primary are strong for the assigned type. Those of the secondary may be slightly *weak* for the assigned type.

^b The stars referred to here as A and B are indicated respectively as B and A in the ADS catalogue.

^c The hydrogen lines of the secondary are strong in comparison with those of the MK standard μ Herculis, as is true of most of the stars called G5 IV by the writer.

^d λ 4215 is strong in the spectrum of the secondary.

^e The published measures of relative position indicate no motion during a period of about 100 years. However, the proper motion is so small that one may nevertheless be uncertain that the system is a physical binary, to judge from the astrometric data alone. The radial velocity of A is given by Wilson (1953) as -20.0 km/sec. The writer has determined the value -27 ± 6 (pe) km/sec for the radial velocity of B, from one spectrogram having a dispersion of about 75 Å/mm at H γ . Thus spectroscopic material, taken in conjunction with the astrometric data, seems to leave little doubt that the system is a physical one.

^f B appears to be a weak-line star.

^g In both spectra, and especially in that of B, λ 4290 is too strong for the assigned type.

sequence although the nearest thereto, ADS 5706C, was assigned to luminosity class IV-V; this fact further illustrates the tendency of stars off the main sequence not to have dwarf companions of nearly equal luminosity.

The foregoing generalizations appear to be consistent with, but do not establish, the following general

description of stellar evolution: Dwarfs of the same age leave the main sequence roughly in order of decreasing mass and, at least initially, follow courses that do not carry them below their starting point, either in the H-R diagram or in the bolometric magnitude vs effective temperature plane. We have here assumed, of course, that late-type primaries off the main sequence

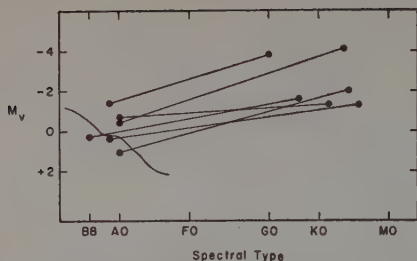


FIG. 2. Visual binaries having secondaries of type AO and earlier. Portions of the solar-neighborhood main sequence indicated in this and following diagrams are based on the data of Keenan and Morgan (1951) or Roman (1952). Primaries are connected by lines with their secondaries.

are at a more advanced stage of evolution than their dwarf secondaries.

We have mentioned several examples of pairs in which both components are above the main sequence, with primaries earlier than secondaries. Several more ex-

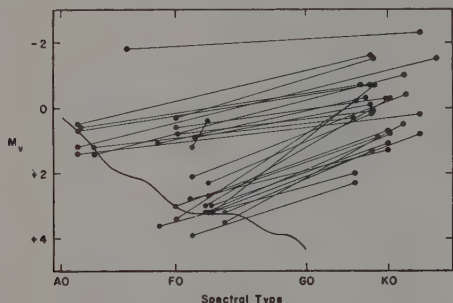


FIG. 3. Binaries having secondaries of types A1 to F4.

amples occur among the subgiants, and they can be identified in Fig. 5 or Table IV. It is of considerable interest to ask if, in such systems, we are observing a binary in which at least one member is evolving to the left in the H-R diagram. The case of 95 Herculis is of particular interest in this connection, because the G-type component of this pair is one of the few stars characterized as a weak-line star by the writer. In fact, he has been very conservative in calling spectra

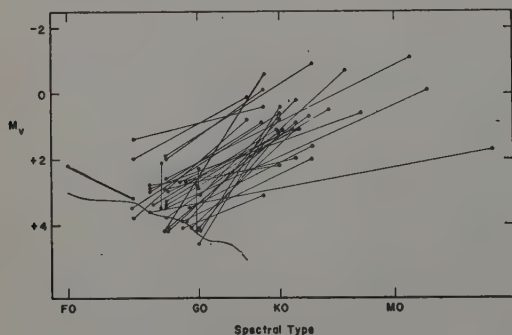


FIG. 4. Binaries having secondaries of types F5 to G0.

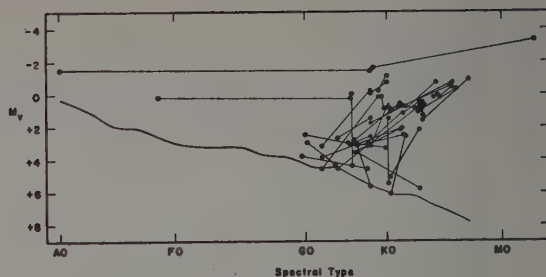


FIG. 5. Binaries having secondaries of types later than G0.

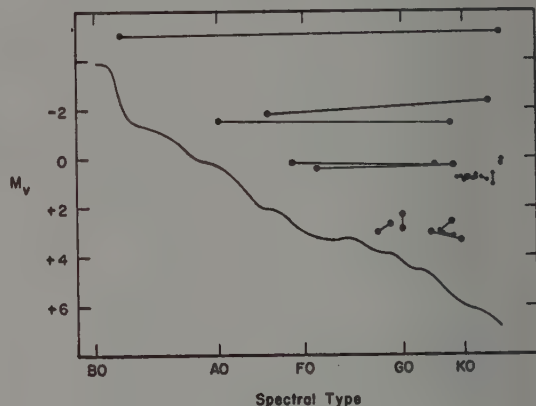


FIG. 6. Binaries for which $\Delta m \leq 0.5$ mag.

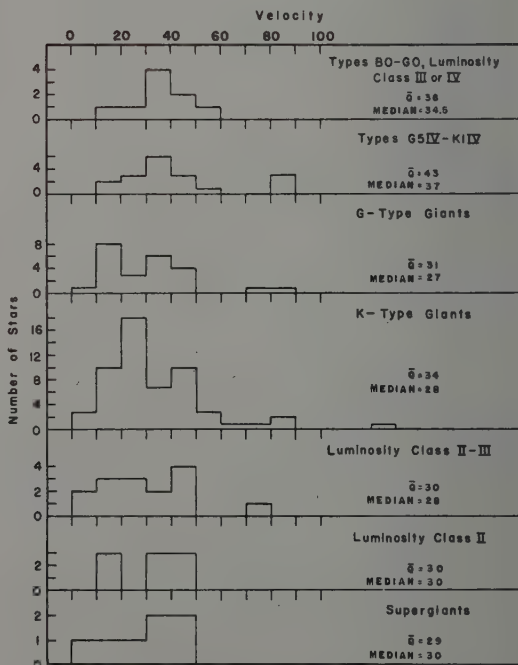


FIG. 7. Space velocities of visual binaries as a function of the spectral types involved.

strong-lined or weak-lined, and has assigned very few to the latter category and none to the former. The reason is his experience that such characteristics may be spuriously duplicated when a spectrogram is compared with that of a standard star recorded with a slightly different photographic density. If hydrogen-to-metal abundance is a major or decisive factor in producing the strong- or weak-line character of a spectrum, however, then the remarks by Unsöld (1958), about the spectroscopic effects of changing this ratio in the atmospheres of later-type stars, are

relevant. Unsöld's comments suggest that we may be dealing with such objects where the notes to our tables mention anomalous intensities in such strong blends as $\lambda\lambda 4144, 4383$, and 4407 , since these intensities were, in fact, mainly judged in relation to those of the remaining features of the spectrum.

To consider a different property of these binaries, we note that their space velocities are remarkably uniform, as illustrated by Fig. 7, which shows the velocity distribution for binaries containing stars located in several regions of the H-R diagram. All available material has

TABLE V. Dwarf, one-component observed or excluded systems.

ADS or (BDS)	Name, HD, or BD	Sp A	Sp B	Notes
995	ϕ Psc	K0 II-III		
2017	+65°284	G8 V	G9V	
2559**	21448	B1 V	G8 III	
4498	39758/9	Comp: A3+G5-8?	G8 II	
4576AC**	HR 2096	K2 III	K0 III	
5036AC**	5 Lyn	K4 III*	G8 III	
6160**	HR 2879	K0 II-III	F8 V	
(4608)**	HR 3315	K5 III	K1 III	
7419**	82394	K0 III	...	
8616	110026	Am A3 F5	...	
8721	112753		G1 V	
8795	114146	G5p	K3 V	a
...**	HR 5021/HD 115753	A1 IV:†	K2 III:	
9121	123670	Comp: F8+G5?	F8 IV	b
9366**	129868	G5 III	F0 V	
9668	+31°2738	G8 V	K2: V	
9865A, BC**	143315/14	K4 II-III	A7 IV, V; A7 IV, V	c
9910	144087/8	G8 V	K0 V	
10152	WW Dra	sgG2, sgK0 ^o	F8 V	d
10323	HR 6343	A+B=K4p	...	e
10419	HR 6404	K1 III	...	
11325	21 Sgr	K2 II	...	
11547	+15°3530	G5 IV	...	
...	BB Sgr/HD 174403	variable	B6 IV, V†	f
11914	+29°3429	G0 V	...	
(9186)**	θ Lyr/+37°3399	K0 II ^o	K2 III	
12322**	181386	G5 II	K0 III†	
12328	181658/7	Comp: ~K3 III+A	Comp: gA+gF?	
12900**	HR 7530/+34°3702	K0 II-III	A2 V	
13318**	190466/+37°3743	M3 II-III:	A2 V	
13554AC**	31 Cyg/HD 192578	K2 II+B3 V ^u	A3 V	
14158	49 Cyg	G8 II	...	
14345AB**	198624	M4 II-III	F7 V:	
14885AC**	203416	M5 II	F5 IV:	
14941	203918	G0 IV	...	
15407	HR 8361	Am	Am	g
15639	209965	F8 V-	...	
(11361)**	208411/376	G8 II	A3 V	
15950	212873	G1 V	G2 V	
(12511)	104 Aqr/HD 222561	G0 Ib	A3p	h

* The luminosity criteria in the spectrum of A are conflicting. The strength of $\lambda 4078$ in particular suggests a higher luminosity than is indicated by the type of B in conjunction with the observed Δm .

^b The secondary is Aitken's component C.

^c The spectra indicate that BC, which is presumably physical, does not form a physical system with A.

^d The primary is an eclipsing variable. Eggen (1955b) has derived a Δm of 0.2 mag from the photometric elements of Plaut (1940). The Δm of AB is about 1.0 mag (Ag, As, A), which yields absolute magnitudes of the components of A of about +3.6 and +3.8.

^e K4 III with weak CN.

^f W. P. Bidelman pointed out to the writer that the similarity in radial velocities and proper motions of these two stars, of which the brighter is a cepheid variable, suggests that they form a physical double star. The writer has compared the two stars photoelectrically with the Lick 12-in. refractor and, on the basis of these observations and the recent elements by Walraven, Muller, and Oosterhoff (1958), concludes that the visual Δm is 0.74 mag at maximum light. An accurate determination of luminosity class is difficult at the spectral type of the secondary, especially with the dispersion used; but the B star seems definitely fainter than a giant. Hence, it seems unlikely, though not entirely impossible, that the system is physical.

^g Both components are metallic-line stars similar to 15 Ursae Majoris. In each spectrum the K-line type approximates A2, and the metallic lines yield a type of about F3.

^h There are strong features in the spectrum of B at $\lambda\lambda 4078, 4172$, and 4325 ; the spectrum almost looks composite.

been included in the counts, but a few high velocities were omitted when these resulted from uncertain proper motions. The method of classifying the data for Fig. 7 is by no means the only possible one, but it is plain that no strong correlation between spectral type and space velocity exists for these stars. It may be worth mentioning, however, that high-velocity stars were not always found to have abnormal spectra. Also, to avoid *a priori* prejudice, all the spectra were examined and classified before the space velocities were computed.

Table V includes systems, not discussed above, whose primaries were observed but whose secondaries proved impossible to observe satisfactorily. A double asterisk (**) indicates a system that was excluded by reason of being optical, probably optical, or of uncertain character; other symbols and abbreviations are as before.

(b) *Relations between linear separations and astrophysical parameters.* Since it seems likely that the frequency distributions of Δm and of spectral type of the secondary, each as a function of the spectral type of the primary, are greatly affected by observational selection, we have not undertaken to determine them explicitly. Furthermore, the distribution of the linear separations of the components must have been subjected to a winnowing process not much less intense than that experienced by the spectrophotometric parameters. Nevertheless, it is possible to isolate from these data a sample of stars within which the observational limitations probably have not altered the functional relationships existing between the several parameters of interest and the linear separation. Unfortunately, however, we do not have a value of the true linear separation for a single one of the systems in this study. Thus we must deal exclusively with the projections of these separations upon the plane at right angles to the line of sight.

We shall restrict the discussion to values of $\Delta m \leq 3.75$ mag and to apparent separations $\rho \geq 5''$, at which separation we were just able to record the pure spectrum of a secondary in good seeing for a system having a Δm of 3.75 mag. If, further, only primaries no fainter than visual magnitude 6.5 are considered, we have defined a set of limiting values for the various parameters within which our observational technique has exhibited essentially no preference for one system over another: of these systems, all have been observed of whose existence we were aware. The observing list already contains correlations between various quantities and distance from the sun, but this circumstance should not seriously affect the functional relationships being investigated, so long as the interdependences are the same from one region of space to another. Our primary interest is in trends dependent upon separation rather than in the actual frequency distribution of any parameter.

The sample as defined above contains 46 pairs, all taken from Bidelman's discussion and from the present observations. There is little dependence of separation

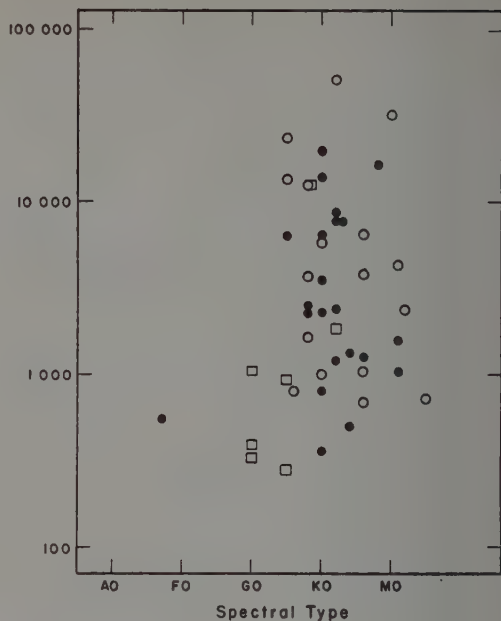


FIG. 8. Projected separation of components as a function of spectral type of the primary, for a sample of binaries for which $\rho'' \geq 5$ sec, $\Delta m \leq 3.75$ mag, and $m_A \leq 6.5$. Open circles: stars of luminosity classes II–III or brighter; dots: class III; squares: classes III–IV or fainter.

on parallax, apart from the effect of the limiting apparent separation.

Figure 8 shows the relation between spectral type of the primary and the projected separation. It should be mentioned that this diagram and the following ones contain the pair with the largest projected separation of any in this set of binaries that has been called a physical system, viz. HR 3590. This double star, which was included in Bidelman's discussion, appears to have a projected separation of at least 50 000 a.u.

It is difficult to be sure of the significance of the concentration of the subgiants in Fig. 8 at separations that tend to be avoided by other primaries. The sub-

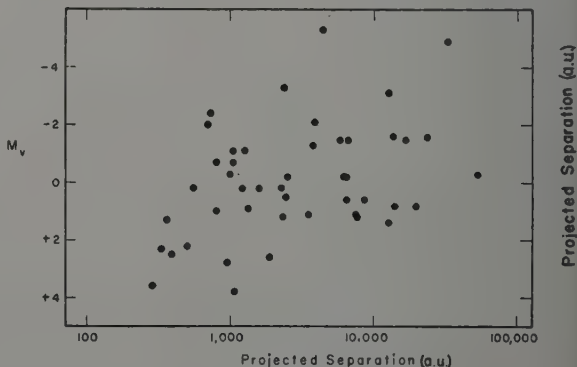


FIG. 9. Visual absolute magnitude of the primary as a function of projected separation, for the sample of Fig. 8.

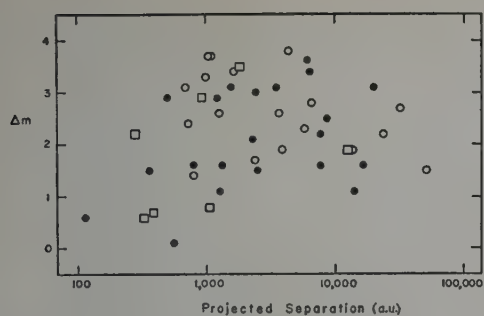


FIG. 10. Visual Δm as a function of spectral type, for the stars of Fig. 8.

giants were taken from a much smaller volume of space around the sun than were the more luminous stars, and accordingly the latter group has suffered a greater depletion of small separations than have the subgiants. However, this may not be the complete explanation. But except for the distribution of the subgiants, Fig. 8 is remarkably free of any trends depending on separation of the binary components.

A similar situation exists in Fig. 9, in which the slight tendency of the higher luminosities to have large separations may be due to the necessity of going to larger distances in order to include the higher luminosity stars; obviously, at the larger distances, only the wider pairs will be observable.

Figure 10 indicates that any dependence of visual Δm on separation is slight. Corresponding plots of bolometric Δm and combined bolometric absolute magnitude exhibit a similar degree of independence of the bolometric quantities on separation. Thus, if there exists any kind of mass-luminosity relation at all for stars above the main sequence, the mass-ratios and combined masses in these systems must be nearly independent of separation.

(c) *The true frequency distribution of the separations.* We shall attempt to estimate the frequency of occurrence of different separations among these wide pairs with respect to a unit volume of space, although this is a difficult problem to treat realistically, because of the operation of selection effects. Thus small separations will appear spuriously rare because, first, they cannot be observed at all at large distances, and second, because among the binaries in the present sample at a given distance, small separations occur in association with a smaller range of values of Δm than do the larger separations. The second point has been dealt with by restricting the sample to a maximum Δm equal to the largest value that could be observed for the smallest

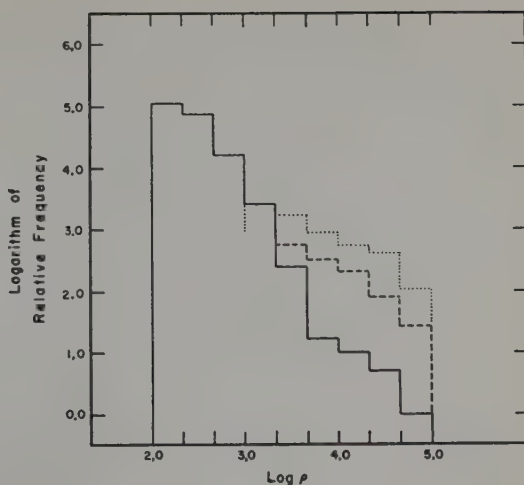


FIG. 11. Frequency of projected separation, for a sample of binaries for which $\rho'' \geq 5''$ and $\Delta m \leq 3.75$. Surveys to three different limiting distances from the sun are indicated by: solid line, to 1500 pcs; dashed line, to 500 pcs; dotted line, to 300 pcs.

angular separation included, as in the previous discussion. This procedure places the entire burden of correcting for selection upon the solution of the first problem, which is in turn simplified by our conclusion that the separation of the components is not related to the luminosity of the primary. For this permits correction for the effect of small separations being lost at great distances by multiplication of the small-separation count by the ratio of the maximum volume encompassed by the whole survey to the volume within which a given small separation is observable.

The conclusion that the astrophysical parameters bear little relation to the separations makes it possible to use a larger sample than that of the preceding discussion because primaries fainter than magnitude 6.5 may be included. Enlarging the sample in this way, we are able to consider 100 binaries. These binaries were counted in intervals of 0.33 in the logarithm of ρ , the projected linear separation in astronomical units, with the results given in Table VI. These binaries lie at distances from the sun up to 1.5 kpc, and the slightly smoothed counts were corrected to this volume in the manner described. The reduced relative frequencies are represented by the solid-line histogram in Fig. 11.

Since it is important to test the influence of the limiting distance of the survey in this analysis, the counts were repeated for the 92 pairs of the initial sample that are within 500 parsecs of the sun. These numbers were reduced to a volume of 500 parsecs in

TABLE VI. Observed distribution of projected linear separations.

$\log \rho$	2.0-2.33	2.33-2.67	2.67-3.0	3.0-3.33	3.33-3.67	3.67-4.0	4.0-4.33	4.33-4.67	4.67-5.0
Number	1	7	14	24	23	15	11	4	1

the same manner as the numbers in the first count were reduced to 1500 parsecs, with the results shown by the dashed line in Fig. 11. The distribution was reduced to the arbitrary ordinate of the first survey at the 1000 to 2155 a.u. ($\log p = 3.0$ to 3.33) interval, and coincides with it for all smaller separations since these counts were unchanged. Finally, the dotted line shows the distribution for a survey limit of 300 parsecs, again fitted to the previous value at the 1000 to 2155 a.u. interval; if separations smaller than 1000 a.u. are omitted, then all of the correction factors are unity. Thus the distribution for separations larger than 1000 a.u. in the 300 pc sample is free of any space density effects. In every instance, the frequency of the projected separations diminishes more rapidly with increasing separation than does the distribution derived by Kuiper (1935) for dwarf systems, although the slope of the 300 pc sample does not differ greatly from that which he found for the same interval of projected separation.

It is obvious that the frequency distribution of the separations cannot be reliably derived, except for the feature that larger separations are less common. The differences between the various samples could, but need not, be a consequence of the fact that the probability of recognition of a physical binary decreases with increasing distance from the sun.

VI. IMPROVEMENT OF THE LUMINOSITY CALIBRATION

The possibility of using visual binaries for checking the luminosity calibration of the MK spectral types is evident. However, some attention must first be given to the question of whether or not the stars of the sample are sufficiently typical. We note at the outset that we are dealing only with binary stars of normal spectra, and except for the usual question of the validity of the hypothesis of uniformity, the only serious danger is that a bias of some sort has been introduced by observational selection. Any relevant bias should manifest itself as a correlation between the residuals, $\Delta m - \Delta m_{sp} = dm$, and either or both of the quantities

Δm and the angular separation, ρ'' , of the components. The quantity Δm_{sp} is the difference between the mean absolute magnitudes of the spectral types to which the components of a particular binary belong.

No significant correlation was found between dm and ρ'' and Δm , either from plots of one quantity against another, or from calculation of the partial and total correlation coefficients, the largest being 0.036. Therefore, the sample appears to be a safe one to use for a revision of the luminosity calibration.

As an initial assumption, the existing calibration for luminosity class V was accepted as correct for stars of type A0 and later. The calibration then proceeded successively by luminosity class: first, the mean absolute magnitude of luminosity class IV stars was adjusted so that $\Sigma dm = 0$ for all pairs involving such a star as primary with a dwarf secondary. Next, the process was repeated for luminosity class III primaries having secondaries of luminosity classes IV or V, and so on, for class II–III up through luminosity class II. The preliminary luminosity calibration adopted for all of the spectral groups studied was that of Miss Roman (1952), except for G5 III and M stars of class II, for which the values given by Keenan and Morgan (1951) were used. By comparison of the new results with the preliminary calibration, the indicated luminosity changes given in the second column of Table VII were obtained. In forming the means, relative weights were assigned according to the presumed mean errors of the Δm 's. The finally adopted corrections to the preliminary calibration are given in the last column of Table VII, and result from a somewhat arbitrary assignment of relative weights to the previous and new results. All of the available double stars in both Bidelman's paper and the present work were utilized, including single-line spectroscopic binaries; but peculiar stars, as well as those of normal spectral types falling entirely outside the definition of the groups studied, were excluded. On the basis of these luminosity corrections, Table VIII gives the mean visual absolute magnitudes adopted for the present study.

TABLE VII. Corrections given by double stars to the luminosity calibration.

MK Spectral Type	Correction to M_v given by double stars (mag)	No. of stars	No. of Stars Roman (1952)	Adopted Correction (mag)
G5 IV–G8 IV	-0.27 ± 0.19 me	10	6(G5–K0)	-0.2
K1 IV	-0.27 0.09	4	3	-0.2
G5 III	-0.24 0.22	4	...	0.0
G8 III	-0.04 0.27	8	65	0.0
K0 III	$+0.37$ 0.10	18	86	+0.1
K1 III	-0.03 0.20	8	32	0.0
K2 III	$+0.15$ 0.37	10	61	0.0
K3 III	$+0.35$ 0.27	4	59	0.0
K4 III	-0.64 0.24	4	31	-0.1
G5 II–III—	$+0.33$ 0.26	12	9	+0.2
K0 II–III				
K1 II–III—	-0.13 0.34	5	14	0.0
K4 II–III				
G5 II–M3 II	$+1.32$ 0.17	8	34	+0.8

It should be emphasized that the newly-determined absolute magnitudes in Table VIII are not to be regarded as based on double stars alone, but on double stars plus single stars used in Miss Roman's discussion. The rather small changes resulting from the introduction of the double star material are shown in Fig. 12. It is of considerable interest that Miss Roman's determination of the shape of the mean luminosity curve for the giants (luminosity class III) is completely confirmed by the double-star material. Likewise, her assignment of a higher luminosity to type K1 IV than to K0 IV is verified for these subgiants.

VII. THE DISPERSION IN LUMINOSITY AT A GIVEN SPECTRAL TYPE

(a) *Analysis of double stars.* Double stars of known MK types provide a means for a determination of the approximate spread in absolute magnitude present in a random sample of stars, all of which have been assigned the same MK type by standard methods of spectral classification at moderate dispersion. According to the amount of material available, the pairs may be considered to be composed of various groups of spectral types (with unlimited material, each group would consist of a single spectral type), each characterized by a standard deviation, σ , which measures the dispersion of the absolute magnitudes of the member stars. If one knows the law of combination of the σ 's that yields the dispersion that will be obtained for the magnitude differs when the groups are observed in pairs, then the σ 's may be obtained from the dispersion in Δm 's.

The assumption that the luminosities are normally distributed about their means is consistent with the observations, because the Δm 's, as defined above in Sec. VI, are distributed approximately normally when the revised luminosity calibration is used; further indications of a roughly normal distribution of luminosities appear from the analysis of trigonometric parallaxes in subsection (b) below. We shall, therefore, suppose that the variance in Δm for a set of binaries whose components belong to two spectral groups is the sum of the variances of the luminosities of the members of

TABLE VIII. Adopted visual absolute magnitudes.

Type	IV	III	II-III	II
G5	+3.0	+0.2	-0.8	-1.8
G8	+3.3	0.0	-0.8	-1.8
K0	+3.3	+0.8	-0.6	-1.8
K1	+2.7	+0.8	-0.8	-1.8
K2		+0.9	-0.8	-1.8
K3		+0.1	-1.0	-1.8
K4		-0.2	-1.0	-1.8
K5		-0.2	-1.0	-1.8
M0		-0.4		-1.6
M1		-0.4		-1.6
M2		-0.4		-1.6
M3		-0.5		-1.6

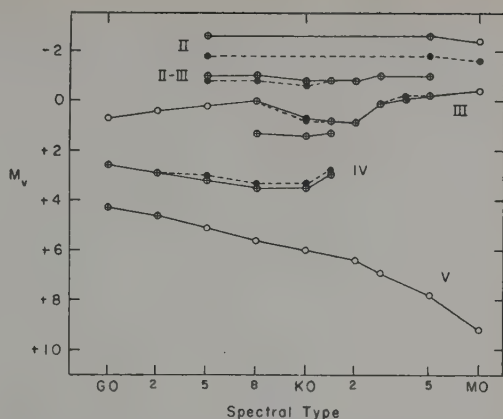


FIG. 12. Calibration of the MK luminosity classes. Open circles: visual absolute magnitudes by Keenan and Morgan (1951); crossed circles: data by Miss Roman (1952); dotted lines: revision from the present investigation.

the component groups. The solution for the variances of n spectral groups, therefore, requires that these groups occur in binaries in at least n combinations; but, in general, there will be more than n combinations, and the solution may be carried out by least-squares.

The correction of the observed variances for observational errors, which is a necessary preliminary to the solution just mentioned, is quite straightforward for normal distributions. If the observed standard deviation is σ , the standard deviation of the quantity being observed is σ_* , and the standard deviation of the observational errors is σ_0 , then for a sufficiently large number of observations we have the well-known relation

$$\sigma^2 = \sigma_*^2 + \sigma_0^2. \quad (3)$$

Since the mean luminosities are assumed given, σ^2 is calculated as the arithmetic mean of $(\Delta m)^2$, regardless of the precision of the photometric observations. If these observations differ among themselves in precision, σ_0^2 is calculated from the mean errors of the observations in exactly the same manner as if the errors were residuals in the ordinary expression for variance about a known mean, i.e., if n_i observations are assigned mean error σ_i , then

$$\sigma_0^2 = \Sigma n_i \sigma_i^2 / \Sigma n_i. \quad (4)$$

This procedure is readily shown to be equivalent to taking a mean of solutions of Eq. (3) for groups of common σ_0 , weighted according to the population of each group. This discussion is, of course, also applicable to the corresponding analysis of trigonometric parallaxes that follows.

The double star material was analyzed, in the manner outlined above, to obtain dispersions in luminosity for eight spectral groups; the results are given in Sec. VII(c). All available material was used, and the same

mean errors for the Δm 's were used as in the foregoing luminosity calibration discussion. The eight normal equations were formed from 24 observation equations, the latter weighted according to the number of pairs involved.

One of the observation equations was obtained in the form of a value of the variance for the main sequence between F5 and K7, based on dwarf binaries having known MK types for both components in this range. A few of these types had been determined by the writer, and were listed in Table V. The remaining systems, comprising fourteen pairs, were taken from the literature.

(b) *Analysis of trigonometric parallaxes.* It is also possible to utilize stars having well-determined trigonometric parallaxes to determine the dispersion in luminosity at a given spectral type. We have already discussed the problem of correcting the observed dispersion for observational error in order to derive the intrinsic dispersion. The errors of the trigonometric parallaxes used have been assumed to be given by the probable errors published in Miss Jenkins' catalogue (Jenkins 1952). These in turn lead to the observational errors in the inferred absolute magnitudes.

In order to avoid use of Eq. (3) to calculate a moderately large value of σ_* from very large values of σ and σ_0 , it is necessary to disregard parallax determinations with mean errors that are large either in actual value or in percentage. The avoidance of large percentage errors in turn introduces a bias, in the sense that the mean value of the observed parallax becomes too large by favoring positive errors over negative ones. Thus, if a sample of stars in which each star has a parallax of

0".040 is observed with a mean error of $\pm 0".015$, and if one derives a mean parallax only from the parallax determinations that have a mean error less than 23% of the observed value (corresponding to the presently contemplated maximum of $\pm 0".005$ me in the absolute magnitudes), then the mean parallax derived for the group would be 0".070, and the inferred absolute magnitude would be 0.6 mag too faint. Although methods have been developed for coping with this effect (cf. Trumpler and Weaver 1953), for the present analysis we have preferred to reject the biased data entirely. We have retained only those stars for which spuriously large distance determinations are not favored to an extent much greater than 0.1 mag in the distance modulus.

The following calculations used trigonometric parallaxes satisfying the following conditions: (1) the parallax was determined at two or more observatories; (2) the mean error, obtained from the probable error assigned by Miss Jenkins, is not greater than $\pm 0".010$; (3) the mean error in the derived absolute magnitude is not greater than ± 0.5 mag; (4) regardless of the size of the mean error, the measured parallax is not less than 0".030. These conditions naturally restrict seriously the number of available trigonometric parallaxes; moreover, some determinations were excluded for which the assigned probable errors seemed entirely too small in view of the disagreement between different determinations. The resulting sample should be reasonably safe to use for the purpose at hand.

Since convenient compilation of trigonometric parallaxes that closely meets the desired requirements already exists in O. J. Eggen's papers (Eggen 1955a,

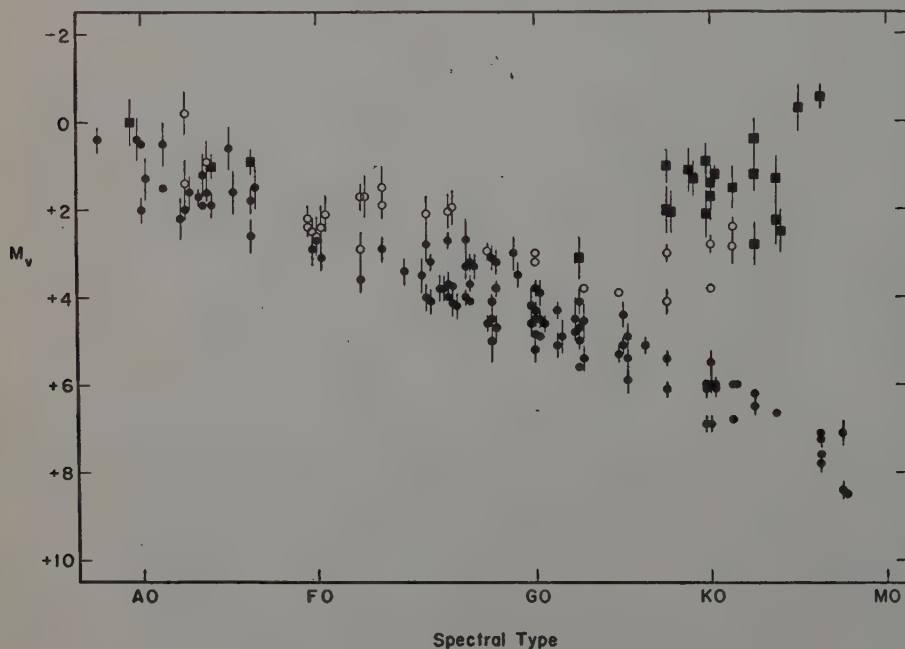


FIG. 13. H-R diagram for stars having well-determined MK types and trigonometric parallaxes used in the calculation of luminosity dispersions. Dots: luminosity class V; open circles: class IV; squares: class III. The lengths of the vertical lines through the points represent twice the luminosity mean errors obtained from published parallax probable errors; the absence of a line indicates a mean error $\leq \pm 0.1$ mag.

1957) on the color-magnitude array for the solar neighborhood, his lists were used as source material. In the present sample, however, only stars having published spectral types on the MK system were included; some of the types listed by Eggen were omitted, and others were added from the literature.

Figure 13 shows the distribution of the luminosities of the stars included in the present calculation of luminosity dispersion from trigonometric parallaxes. Although the diagram has considerable interest as an H-R diagram for solar-neighborhood stars having well-determined absolute magnitudes and spectral types, the intermediate luminosity classes III-IV and IV-V, which were not included in the calculations, are not plotted. The diagram suggests no strong violation of the normal-distribution approximation.

(c) *Discussion.* Table IX summarizes the results of the luminosity-dispersion analyses of double stars and trigonometric parallaxes. The means are averages of the variances found from the two sources of data, with the double star results given twice as much weight. Trigonometric values for giants earlier than KO are given for comparison only, although they were included in the averages as if they had been introduced directly into a least-squares solution involving both kinds of observations. Probable errors of the determinations were not calculated. The table gives standard deviations in magnitudes: σ_D and σ_π refer respectively to double-star and trigonometric parallax results.

Several points of interest in Table IX may be noted. First, the agreement between results from the double-star material and from the trigonometric parallaxes is good only for luminosity class V, where the general principles used appear to be vindicated. The sense of the difference for other classes suggests that the mean errors assigned to the generally small giant and subgiant trigonometric parallaxes probably are too small. Second, the dispersions are not always proportional in size to the intervals between the lines of mean luminosity in the H-R diagram. The early subgiants do conform to this proportionality, while the later subgiants do not. The example cited does not, however, prove the existence of a sequence of late subgiants; it shows only that the spectroscopic criteria of luminosity are sufficiently sensitive in the region of the later type

subgiants that stars far enough removed from the mean-luminosity line are assigned intermediate types. Third, no significant variation in the width of the main sequence was found, so far as the crude subdivision into two halves that was performed here is concerned. It is important to remember that, in the present context, we mean only luminosity class V when we refer to the "main sequence". Since we are not dealing with a Hess diagram, these results are not of direct relevance to evolutionary arguments, and the dispersions derived are measured only of the scatter in the relation between absolute magnitude and spectral appearance. In fact, however, stars of luminosity class IV-V are rather rare in comparison with those of class V, as are the subdwarfs. Thus, even in the context of a Hess diagram, the present results indicate that the solar-neighborhood main sequence has a width, 2σ , equal to about one magnitude. In this sense, two-thirds or more of all the stars that define the main sequence are confined to a band one magnitude wide in luminosity.

Finally, from the information in Table IX, we conclude that, within the region of the H-R plane occupied by the stars of the table, there is no gross variation in the precision with which the position of a star in the plane can be located by means of visual spectral classification.

The most direct evidence for the presence or absence of preferred luminosities among the components of double stars is that contained in Fig. 14. This is an H-R diagram for all of the Stephenson-Bidelman stars that were assigned positions in a spectrum-luminosity plot. Unfortunately, any real luminosity concentrations would be blurred by the adjustment of the absolute magnitudes of binary components that was performed in order to secure agreement with observed Δm 's. Nevertheless, it is only this treatment of the data that gives a semi-fundamental character to the luminosities. Still less is Fig. 14 indicative of luminosities within a representative volume of space. For example, of necessity, there must be in this sample fewer stars on the main sequence than off it. On the other hand, the diagram may be roughly characteristic of a volume of space for stars well removed from the main sequence, even

TABLE IX. Dispersions in luminosity.

Spectral Type	σ_D (mag)	No. Stars	σ_π (mag)	No. Stars	Mean σ (mag)	Total No. Stars
B8 V-F4 V	± 0.51	24	± 0.54	26	± 0.51	50
F5 V-K7 V	0.37	68	0.45	82	0.40	150
A2 IV-F6 IV	...	...	0.29	17	0.29	17
F7 IV-K1 IV	0.35	28	0.65	11	0.41	39
B9.5 III-F9 III	0.43	11	1.27	3	0.60	14
G0 III-G9 III	0.39	16	1.65	6	0.74	22
K0 III-K5 III	0.48	55	1.10	14	0.58	69
G5 II-III-M2 II-III	0.63	19	...	...	0.63	19
A4 II-M3 II	0.57	9	...	...	0.57	9

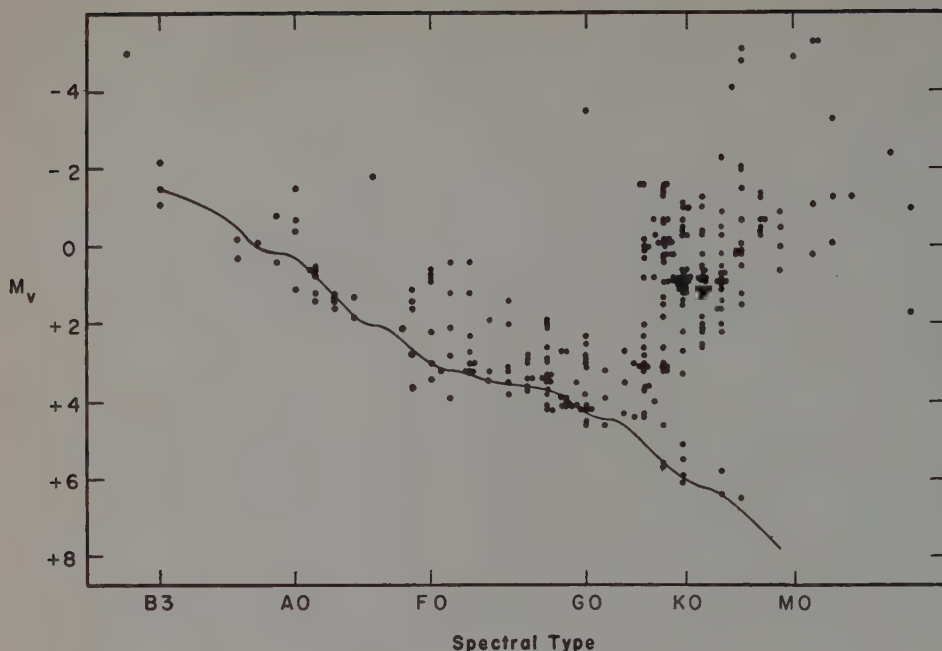


FIG. 14. H-R diagram for all the normal stars discussed in this paper.

though these cannot be compared for relative frequency when they differ greatly in absolute magnitude.

With these reservations in mind, Fig. 14 shows some features of interest. One is a sharply defined, wedge-shaped Hertzsprung gap. The fairly smooth progression of dwarfs and subgiants across the gap spectral types plus the fact that the spectral types represent continuous sequences of color indices for the various luminosities, means that the sharpness of the gap boundary does not result from the system of spectral classification. Second, there is the well-known absence, or rarity, of subgiants later than K1 or K2, and the indication of a lower limiting envelope to the entire giant region. A giant sequence is suggested, with a shape similar to that of the mean luminosity curve for the giants. The K0 giants seem to be more numerous than any other stars off the main sequence, and there may be a slight tendency for subgiants of types G5 and G8 to concentrate near $M_v = +3.1$. The scarcity of red dwarfs is undoubtedly one indication of observational selection.

VIII. THE MASS PROBLEM

(a) *Procedure.* The fact that the present investigation has furnished improved distances for many binaries containing giants, and the fact that it also has provided spectral types for the components of these systems, are reasons to attempt to derive masses by a statistical treatment of the observed relative motions.

The method adopted involves the comparison of spectroscopic and "hypothetical" parallaxes. The latter are computed from the relative motion of the

components of a binary by assigning to the system a total mass of one solar mass, and by assuming certain mean properties of the relative orbit: its dynamical elements, its orientation, and the position of the companion therein at the time of observation. The basic method has been employed before (Seares 1922; Russell, Adams, and Joy 1923; Russell and Moore 1940a), but with generally unsatisfactory results for giants.

The statistical theory used is that of H. N. Russell (Russell and Moore 1940a). This theory has been severely criticized by J. Hopmann (1955). His criticism is based on a regression equation relating observed motion at a particular epoch with known masses and so-called *strahlungsenergetische* parallaxes for a large sample of binaries. The sample of binaries is subject to selection effects, noted by Hopmann himself, of types which Russell had already stated could vitiate his statistical treatment, e.g., the orbits based on less than one complete revolution were preferentially calculated for stars near periastron at the present time. Consequently it does not seem reasonable to base objections to the Russell theory upon discussions such as Hopmann's. Moreover, for the systems analyzed below for mass evaluation, the mean of the Russell-Moore dynamical parallaxes, weighted according to Russell's precepts, is $\bar{\pi}_d = 0''.0092$, while the spectroscopic mean is $\bar{\pi}_{sp} = 0''.0089$. Although this result does not insure that the masses will be reliable, it does not support Hopmann's position. The means for $p < 0.010$ are $\bar{\pi}_d = 0''.0068$ and $\bar{\pi}_{sp} = 0''.0050$. Nevertheless, we must return eventually to the question of whether or not observational selection, which can take many forms,

may have made the binaries of the present sample incapable of being treated correctly by the Russell theory of mass evaluation.

The procedure used in the present investigation differs from that of Russell in several respects. The most important differences are that mean masses for several areas of the H-R plane were sought rather than a gross mean mass for all stars above the main sequence, and masses of secondaries were dealt with as unknowns rather than being estimated from magnitude differences and an assumed mass-luminosity relation. Six cells were delineated in the H-R plane in such a way as to make the fullest use of the available data, and a solution was made for the mean mass corresponding to each cell. Masses of dwarf components were assumed known, and known spectroscopic binaries were excluded. The observational material for the systems used in the calculation of masses was made as complete as necessary with respect to relevant photometric and interstellar-absorption data, as mentioned earlier. Moreover, some new hypothetical parallaxes were determined by the writer for pairs for which adequate observations had become available since the Russell-Moore compilation, and all of the observed relative motions employed by Russell and Moore (1929, 1940c) in their computations were checked for consistency against the comprehensive Lick file of double-star observations being compiled under the direction of Dr. H. M. Jeffers. Ninety-eight individual stars were employed in all. It will be noted immediately below that the mass values found in this way were implausible, and, although it will be shown that our deviations from Russell's method are not at fault, the unsuccessful

nature of the calculation accounts for the omission here of further details of the numerical procedure.

(b) *Discussion.* Figure 15 shows the outlines of the cells into which the H-R plane was divided. A few individual stellar masses that are supposed to be fairly accurately known for stars off the main sequence (Strand and Hall 1954, Strand 1957) are shown in this diagram as the numbers adjacent to the filled circles. The mean positions of the stars defining the cells are indicated by crosses, and the derived mean mass of a cell member is given, in solar units, by a number in each cell.

To what extent undiscovered spectroscopic binaries may affect these results is uncertain, but it seems probable that the derived masses are too large. The largest mass occurs for cell F, for which $\bar{\pi}_{sp}$ has the smallest value. This result suggests that the mean motions are not representative; in fact, for cell F we have $\bar{\pi}_d = 0''.0055$, while $\bar{\pi}_{sp} = 0''.0036$. Here we seem to have an obvious failure to meet statistical theory requirements.

The great majority of Russell's giant pairs have apparent separations too small to permit their inclusion in the present investigation, and many others involve spectroscopic binaries. In all, only 25 of his giant systems are in common with the present list, excluding those for which the writer re-derived the hypothetical parallax. With Russell's Eq. (90) (Russell and Moore 1940a) and his own numerical data, $\bar{M}_i$ for the 25 pairs in question is found to be 2.50 solar masses, a value much larger than his mean value for the whole group of giants. The present treatment of the same 25 doubles yields $\bar{M}_i = 2.34$; for the entire sample, including some

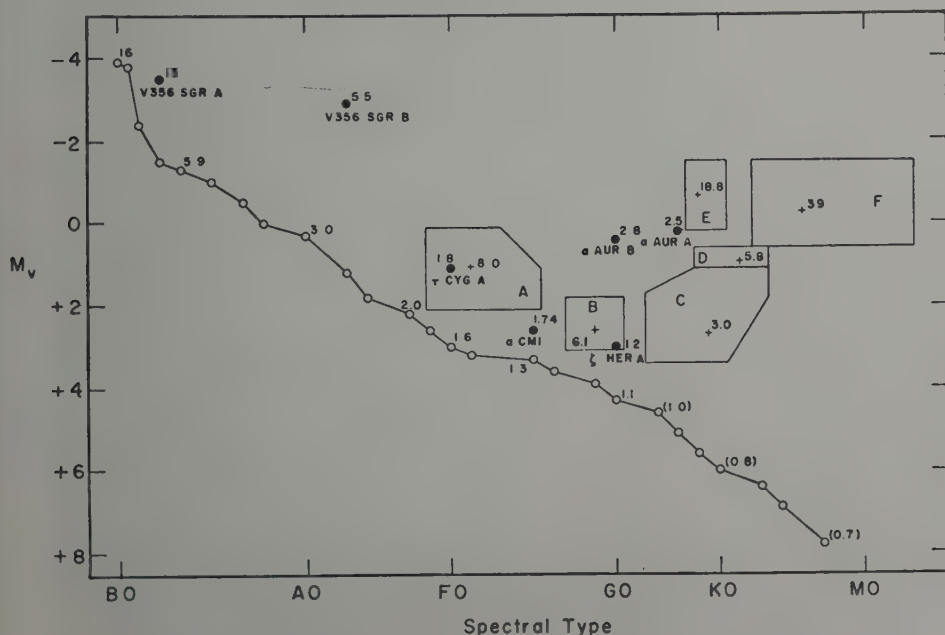


FIG. 15. Cells into which the H-R plane was divided for the calculation of stellar masses. See text (Sec. VIIIa) for explanation.

subgiant primaries, $\overline{M_1}=2.30$. It seems clear that the abnormally high masses do not result from our deviation from Russell's method of analysis.

Looking for differences between the 25 pairs in common and the remainder of Russell's stars, we find one that is fairly outstanding. The pairs common to both lists have *much greater linear separations* than do the remainder of the stars in Russell's sample. Not one pair in the group in common has a projected separation smaller than 150 a.u., while more than a third of Russell's remaining pairs are closer than this; the mean projected separation of the former group is in excess of 1300 a.u., while that of the latter is less than 500. This is the natural result of our having considered only those binaries for which the spectra of both components could be well observed. If the semimajor axes of each group are on the average proportional to the projected separations, the mean relative motions (for equal masses) would differ by a factor of about $4\frac{1}{2}$ between the two groups, in general agreement with the published motions. This effect is plainly evident in the derived masses, where systematic errors are effectively cubed. Since, of course, no large exponent affects the parallaxes, they do not appear to be so bad, although we have noted that the dynamical parallaxes are systematically too large by 36% for stars having spectroscopic parallaxes smaller than 0".01. In view of these considerations, there is little reason to doubt that *the hypothetical parallaxes of the wider binaries are based on nontypical motions*, in the sense that only larger-than-average relative motions are available for the computations. This conclusion is not particularly surprising, and Russell himself was well aware of the danger (Russell and Moore 1940b).

It is also apparent that no satisfactory answer can be given to the question of whether or not Russell's determination of a mean mass for giants would have been better if based only on the closer pairs. The average spectral type to which such a determination would apply is uncertain, and the use of a main-sequence mass-luminosity relation to estimate mass-ratios is likewise questionable. The hypothetical parallaxes should be more reliable for very close pairs, but accurate spectroscopic data will be extremely difficult to obtain, and the foregoing discussion indicates that very accurate mean parallaxes are necessary for the derived masses to have a useful degree of precision.

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Photoelectric Light Curves of V839 Ophiuchi

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Photoelectric observations are presented of 310 yellow and 311 blue magnitudes of V839 Ophiuchi made during the summers of 1958 and 1959. A new period was derived from these observations. The light in the maximum shows a reflection effect ($\cos\theta$ term), which has a sign opposite that expected by theory.

THE variable V839 Ophiuchi was discovered by R. Rigollet (1947), who gave 131 visual estimates. The light variation was found to be of the W Ursae Majoris type. No other photometric or spectroscopic observations have been published for this variable.

This system was observed photoelectrically in the effective wavelengths 5300 Å and 4420 Å with the 28-inch reflecting telescope of the Flower and Cook Observatory during the summers of 1958 and 1959. The observations were made with a 1P21 photomultiplier cell, the output of which was fed into a direct

Tables IIa and IIb give the observations in heliocentric Julian Day, phase counted from primary minimum, and the magnitude difference in the sense of variable minus comparison star. A total of 310 yellow and 311 blue magnitudes were obtained during eight nights.

Table III and Fig. 1 show the normal points of the observations. A zero-point correction of +0.494 for the yellow magnitudes and +0.427 for the blue magnitudes was applied to make the magnitude difference equal to zero at maximum. Primary and secondary minima have nearly the same depths. The question arises as to whether this variable could perhaps be of the RR Lyrae type. However, the spectral type, the measured color, and the small amplitude in the color curve agree in indicating that the system belongs to the W Ursae Majoris type.

The intensity and phase angle of the normal points were computed. It was found that the light in the maxima shows a reflection effect ($\cos\theta$ term) which has a sign opposite from that expected from the theory. The maxima have practically the same height so that the $\sin\theta$ term is very small. The same was found by the author in the systems V566 Ophiuchi and AB Andromedae. However, in three other systems of the W Ursae Majoris type studied systematically by the author, namely 44i Bootis, U Pegasi, and AH Virginis, the expected sign of the reflection effect was found, but the relative height of the maxima changed with time. Undoubtedly, all these effects are caused by gas streams in the systems, but still more observations are needed.

TABLE I. Variable and comparison stars.

Star	BD No.	R.A. (1900)	D. (1900)	Sp.
V839 Oph.	+9°3584	18 ^h 4 ^m 36 ^s *	+9°8'0	G0
Comp. Star	9 3578	18 4 5	9 3.4	F8
Check Star	8 3590	18 3 48	9 0.2	A2

current amplifier, and the amplified current was recorded by a Brown recorder. The duration of one deflection was one minute.

Table I gives the BD number, the position of the stars, and the spectral types of the stars according to the HD Catalogue. The check star was measured about every two hours during the observations and showed a constant magnitude difference with respect to the comparison star.

It was not necessary to apply a correction for differential extinction. The times of minima were computed according to the method of E. Hertzsprung (1928) and found to be as follows:

JD Hel. 2436361.73170 Min. I
 6734.73473 I
 6735.75738 II

The ephemeris was determined from our observations only, and phases were computed from the formula:

Min. I = 2436361.73170 + 0.4089946 E.

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TABLE IIa. Yellow observations of V839 Ophiuchi.

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6361.6954	.9111	-.222	6728.6691	.1694	-.436	6734.7199	.9637	+.006
.6967	.9146	.202	.6706	.1730	.430	.7213	.9671	.030
.6983	.9182	.189	.6722	.1770	.436	.7227	.9705	.036
.6996	.9216	.180	.6738	.1807	.424	.7241	.9739	.040
.7059	.9369	.104	.6801	.1963	.459	.7281	.9838	.076
.7072	.9400	.115	.6817	.2002	.478	.7310	.9908	.067
.7086	.9434	.091	.6834	.2042	.470	.7324	.9942	.067
.7099	.9468	.093	.6891	.2183	.489	.7379	.0076	.072
.7162	.9621	.002	.6906	.2220	.503	.7394	.0112	.063
.7176	.9655	-.003	.6924	.2262	.479	.7422	.0180	.054
.7193	.9697	+.032	.6939	.2299	.491	.7505	.0384	+.008
.7207	.9731	.036	.7073	.2627	.490	.7517	.0415	-.010
.7259	.9858	.052	.7086	.2659	.477	.7533	.0452	.041
.7273	.9892	.068	.7100	.2693	.482	.7545	.0483	.047
.7287	.9926	.070	.7115	.2729	.475	.7616	.0656	.141
.7346	.0071	.080	.7169	.2862	.480	.7630	.0689	.133
.7360	.0105	.075	.7184	.2899	.484	.7644	.0723	.165
.7374	.0139	.071	.7199	.2936	.472	.7656	.0755	.170
.7454	.0334	.030	.7216	.2976	.466	.7671	.0791	.190
.7467	.0368	+.017	.7276	.3122	.436	.7720	.0910	.239
.7481	.0402	-.010	.7291	.3159	.441	.7734	.0944	.256
.7544	.0555	.086	.7307	.3199	.451	.7748	.0978	.267
.7558	.0588	.115	.7324	.3242	.435	.7762	.1012	.282
.7582	.0648	.141	.7385	.3389	.411	6735.6907	.3372	-.415
.7634	.0775	.171	.7398	.3423	.411	.6920	.3406	.411
.7651	.0818	.221	.7417	.3468	.415	.6935	.3442	.414
.7665	.0852	.231	.7433	.3507	.415	.6949	.3476	.406
.7728	.1005	.274	.7501	.3675	.355	.7005	.3612	.380
.7744	.1044	.274	.7518	.3714	.349	.7019	.3646	.364
.7758	.1078	.301	.7534	.3754	.344	.7031	.3677	.359
.7853	.1310	.357	.7599	.3912	.306	.7047	.3714	.338
.7869	.1349	.362	.7614	.3949	.284	.7101	.3847	.317
.8009	.1692	.441	.7630	.3989	.274	.7122	.3898	.297
.8023	.1726	.425	.7645	.4025	.262	.7136	.3932	.290
.8050	.1791	.453	.7705	.4173	.208	.7150	.3966	.282
.8142	.2018	.481	.7726	.4224	.183	.7261	.4237	.178
.8156	.2052	.489	.7741	.4260	.177	.7275	.4271	.175
.8170	.2086	.488	.7755	.4294	.153	.7288	.4305	.164
.8224	.2218	.498	.7813	.4436	.086	.7303	.4342	.145
.8239	.2255	.482	.7829	.4475	.062	.7357	.4472	.080
.8253	.2289	.492	.7844	.4512	.046	.7373	.4512	.056
.8308	.2422	.498	.7859	.4549	-.030	.7386	.4543	.040
.8323	.2459	.494	.7912	.4679	+.022	.7401	.4580	-.029
.8337	.2493	.496	.7930	.4722	.033	.7455	.4713	+.024
.8391	.2626	.501	.7948	.4767	.051	.7484	.4784	.039
.8405	.2660	.493	.7964	.4806	+.054	.7498	.4818	.046
.8420	.2696	.480	6734.6442	.7786	-.503	.7551	.4948	.052
6370.6941	.9133	-.217	.6470	.7854	.504	.7567	.4987	.052
.7004	.9286	.145	.6484	.7888	.480	.7595	.5055	.050
.7018	.9320	.113	.6545	.8038	.479	.7650	.5188	.059
.7038	.9371	.105	.6560	.8075	.470	.7670	.5239	.048
.7052	.9405	.062	.6574	.8109	.459	.7685	.5276	.041
.7122	.9575	-.010	.6588	.8143	.461	.7699	.5310	+.026
.7136	.9608	+.009	.6642	.8276	.425	.7756	.5449	-.019
.7150	.9642	.034	.6658	.8313	.442	.7770	.5483	.042
.7163	.9676	.045	.6671	.8346	.436	.7785	.5519	.069
.7222	.9821	.087	.6685	.8380	.439	.7798	.5551	.079
.7236	.9855	.085	.6740	.8514	.386	.7860	.5703	.158
.7250	.9889	.085	.6755	.8550	.378	.7875	.5740	.177
.7264	.9923	.083	.6769	.8584	.377	.7889	.5774	.195
.7331	.0087	.074	.6783	.8618	.367	.7903	.5808	.204
.7347	.0126	.072	.6845	.8771	.338	.7957	.5941	.257
.7368	.0177	+.056	.6859	.8805	.332	.7972	.5978	.272
6728.6416	.1020	-.285	.6874	.8842	.323	.7986	.6012	.272
.6429	.1051	.298	.7004	.9159	.212	.7999	.6043	.282
.6445	.1091	.311	.7019	.9195	.197	.8061	.6193	.319
.6459	.1125	.313	.7033	.9229	.185	.8074	.6227	.323
.6475	.1164	.317	.7047	.9263	.172	.8088	.6261	.340
.6586	.1436	.394	.7101	.9396	.098	.8102	.6295	.351
.6601	.1473	.398	.7116	.9433	.091	.8220	.6583	.413
.6617	.1512	.399	.7130	.9467	.067	.8234	.6617	.417
.6635	.1555	.412	.7144	.9501	.051	.8250	.6657	.419

TABLE IIa.—Continued.

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6735.8264	.6691	— .424	6783.6391	.5720	— .132	6784.6593	.0664	— .126
.8278	.6725	.436	.6456	.5879	.199	.6610	.0706	.131
6753.7340	.4536	— .026	.6475	.5927	.225	.6625	.0743	.153
.7366	.4598	+ .006	.6494	.5972	.250	.6680	.0876	.204
.7373	.4615	.000	.6557	.6127	.303	.6696	.0916	.224
.7387	.4649	.018	.6571	.6161	.303	.6710	.0950	.227
.7401	.4683	.025	.6585	.6195	.307	.6724	.0984	.240
.7460	.4827	.067	.6599	.6229	.321	.6786	.1137	.285
.7489	.4898	.080	.6724	.6535	.373	.6800	.1171	.295
.7502	.4932	.075	.6738	.6569	.376	.6814	.1204	.307
.7560	.5074	.073	.6773	.6654	.418	.6828	.1238	.322
.7574	.5107	.069	.6899	.6962	.431	.6882	.1371	.348
.7588	.5141	.061	.6912	.6993	.454	.6897	.1408	.365
.7608	.5190	+ .057	.6925	.7027	.457	.6911	.1442	.368
.7733	.5495	— .028	.6939	.7061	.463	.6925	.1476	.381
.7748	.5532	.044	.6996	.7200	.477	.6982	.1615	.399
.7762	.5566	.062	.7010	.7234	.481	.6996	.1649	.408
.7776	.5600	.082	.7031	.7285	.482	.7011	.1686	.417
.7838	.5753	.150	.7044	.7316	.483	.7025	.1720	.421
.7853	.5790	.160	.7099	.7452	.500	.7112	.1935	.450
.7868	.5826	.178	.7119	.7500	.498	.7127	.1971	.449
.7882	.5860	.191	.7135	.7540	.499	.7144	.2011	.452
.7935	.5991	.240	.7152	.7582	.504	.7160	.2051	.464
.7949	.6024	.257	.7209	.7721	.497	.7269	.2317	.483
.7963	.6058	.267	.7224	.7758	.483	.7286	.2359	.481
.8019	.6194	.308	.7239	.7794	.487	.7300	.2393	.481
.8034	.6231	.313	.7252	.7826	.492	.7313	.2424	.484
.8052	.6276	.331	.7320	.7993	.497	.7369	.2563	.472
.8070	.6319	.343	.7336	.8032	.495	.7384	.2600	.477
6783.6339	.5593	— .076	.7351	.8069	.489	.7396	.2628	.479
.6354	.5629	.111	6784.6578	.0672	— .097	.7411	.2665	.480
.6376	.5683	.123						

TABLE IIb. Blue observations of V839 Ophiuchi.

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6361.6961	.9129	— .136	6361.8016	.1709	— .380	6728.6452	.1108	— .250
.6975	.9163	.101	.8033	.1752	.373	.6466	.1142	.252
.6989	.9199	.111	.8057	.1808	.385	.6483	.1184	.239
.7002	.9230	.107	.8148	.2032	.425	.6594	.1456	.334
.7065	.9383	.046	.8162	.2066	.423	.6609	.1493	.338
.7079	.9417	.029	.8176	.2100	.416	.6624	.1530	.340
.7092	.9451	.010	.8231	.2235	.428	.6643	.1575	.362
.7106	.9485	— .003	.8245	.2269	.410	.6699	.1713	.388
.7169	.9638	+ .111	.8259	.2303	.426	.6713	.1747	.384
.7183	.9672	.112	.8315	.2439	.441	.6729	.1787	.392
.7200	.9714	.137	.8329	.2473	.426	.6746	.1827	.402
.7214	.9748	.137	.8344	.2510	.409	.6808	.1979	.415
.7266	.9876	.160	.8398	.2643	.416	.6826	.2022	.415
.7280	.9909	.160	.8412	.2677	.407	.6900	.2203	.429
.7294	.9943	.189	.8426	.2711	.399	.6915	.2240	.432
.7353	.0088	.180	6370.6903	.9040	— .152	.6932	.2282	.424
.7367	.0122	.164	.6948	.9150	.118	.6946	.2316	.437
.7381	.0156	.160	.7011	.9303	.037	.7080	.2644	.423
.7460	.0351	.091	.7025	.9337	— .004	.7093	.2676	.411
.7474	.0385	.080	.7045	.9388	.000	.7108	.2713	.411
.7488	.0419	+ .060	.7066	.9439	+ .035	.7123	.2749	.398
.7551	.0572	— .022	.7129	.9592	.096	.7176	.2879	.413
.7565	.0605	.043	.7143	.9626	.113	.7191	.2916	.404
.7587	.0659	.055	.7157	.9660	.127	.7207	.2956	.383
.7658	.0835	.157	.7170	.9693	.141	.7225	.2998	.392
.7735	.1021	.216	.7230	.9838	.173	.7284	.3143	.374
.7749	.1055	.208	.7243	.9872	.170	.7298	.3177	.378
.7765	.1095	.244	.7257	.9906	.175	.7315	.3219	.367
.7844	.1287	.271	.7271	.9939	+ .168	.7336	.3270	.353
.7860	.1327	.285	6728.6423	.1037	— .219	.7391	.3406	.346
.7876	.1366	.292	.6437	.1071	.232	.7409	.3448	.336

TABLE IIb.—Continued.

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6728.7424	.3485	— .343	6735.6913	.3389	— .338	6753.7970	.6075	— .205
.7442	.3530	.329	.6928	.3425	.330	.8024	.6208	.247
.7511	.3697	.287	.6942	.3459	.326	.8042	.6251	.260
.7526	.3734	.282	.6956	.3493	.313	.8060	.6296	.264
.7540	.3768	.268	.7012	.3629	.297	.8076	.6336	.276
.7607	.3932	.213	.7025	.3660	.285	6783.6347	.5612	— .013
.7621	.3966	.196	.7038	.3694	.272	.6362	.5649	.045
.7637	.4006	.185	.7052	.3728	.257	.6383	.5700	.037
.7653	.4045	.168	.7115	.3881	.231	.6398	.5737	.060
.7718	.4204	.095	.7129	.3915	.226	.6463	.5895	.126
.7733	.4241	.094	.7143	.3949	.202	.6483	.5947	.155
.7748	.4277	.091	.7156	.3983	.210	.6502	.5992	.175
.7762	.4311	— .068	.7269	.4257	.106	.6563	.6142	.225
.7821	.4456	+ .020	.7282	.4289	.099	.6577	.6176	.229
.7837	.4495	.032	.7295	.4322	.076	.6591	.6210	.233
.7851	.4529	.053	.7310	.4359	— .064	.6605	.6244	.244
.7866	.4566	.063	.7365	.4492	+ .016	.6731	.6552	.302
.7920	.4699	.106	.7380	.4529	.042	.6745	.6586	.315
.7939	.4744	.115	.7394	.4563	.058	.6758	.6617	.329
.7955	.4784	.134	.7407	.4594	.072	.6780	.6671	.343
.7971	.4823	+ .135	.7463	.4733	.124	.6905	.6977	.379
6734.6449	.7803	— .451	.7477	.4767	.116	.6919	.7011	.386
.6463	.7837	.431	.7490	.4798	.123	.6932	.7044	.393
.6477	.7871	.416	.7505	.4835	.116	.6946	.7078	.397
.6491	.7905	.417	.7559	.4967	.137	.7004	.7220	.432
.6553	.8058	.411	.7573	.5002	.145	.7017	.7251	.437
.6566	.8089	.403	.7587	.5036	.138	.7035	.7296	.419
.6581	.8126	.392	.7602	.5072	.138	.7050	.7333	.424
.6594	.8157	.377	.7658	.5208	.138	.7106	.7469	.438
.6650	.8293	.370	.7679	.5259	.114	.7128	.7523	.434
.6664	.8329	.380	.7706	.5327	.100	.7144	.7562	.426
.6677	.8361	.363	.7763	.5466	.046	.7158	.7596	.420
.6692	.8397	.377	.7777	.5500	.036	.7217	.7741	.426
.6748	.8533	.327	.7791	.5534	+ .006	.7231	.7774	.406
.6762	.8567	.307	.7812	.5584	— .022	.7245	.7808	.419
.6776	.8601	.309	.7867	.5720	.090	.7258	.7840	.414
.6790	.8635	.306	.7881	.5754	.110	.7328	.8012	.394
.6851	.8785	.264	.7895	.5788	.122	.7343	.8049	.422
.6865	.8819	.246	.7909	.5822	.125	.7356	.8080	.404
.6882	.8861	.230	.7964	.5958	.181	.7371	.8117	.376
.7011	.9176	.128	.7978	.5992	.195	6784.6586	.0647	— .055
.7026	.9212	.122	.7993	.6029	.210	.6602	.0687	.063
.7040	.9246	.096	.8006	.6060	.221	.6617	.0723	.066
.7053	.9280	.090	.8067	.6210	.258	.6633	.0763	.099
.7108	.9413	.021	.8081	.6244	.266	.6688	.0896	.147
.7123	.9450	— .006	.8095	.6278	.280	.6703	.0933	.147
.7137	.9484	+ .003	.8108	.6309	.280	.6717	.0967	.162
.7151	.9518	.029	.8227	.6600	.344	.6729	.0998	.179
.7206	.9654	.084	.8241	.6634	.350	.6793	.1154	.212
.7220	.9688	.098	.8256	.6671	.352	.6807	.1187	.225
.7234	.9722	.115	.8271	.6708	.355	.6821	.1222	.234
.7248	.9756	.132	.8287	.6748	— .374	.6835	.1255	.250
.7289	.9857	.160	6753.7354	.4570	+ .072	.6889	.1388	.289
.7303	.9891	.160	.7380	.4632	.106	.6904	.1425	.296
.7317	.9925	.163	.7395	.4669	.109	.6918	.1459	.317
.7331	.9959	.152	.7406	.4697	.124	.6932	.1493	.316
.7387	.0095	.162	.7469	.4850	.148	.6989	.1632	.350
.7401	.0129	.152	.7482	.4881	.168	.7002	.1666	.347
.7414	.0163	.152	.7495	.4915	.156	.7017	.1702	.347
.7427	.0194	.145	.7509	.4949	.165	.7031	.1736	.358
.7512	.0401	.070	.7567	.5091	.156	.7119	.1952	.398
.7526	.0435	.060	.7581	.5125	.153	.7137	.1994	.384
.7539	.0469	.034	.7595	.5159	.153	.7152	.2031	.411
.7553	.0503	+ .018	.7618	.5215	.161	.7167	.2068	.414
.7608	.0636	— .043	.7755	.5549	.039	.7278	.2339	.434
.7623	.0673	.066	.7767	.5580	+ .028	.7293	.2376	.428
.7637	.0706	.078	.7783	.5617	— .003	.7307	.2410	.415
.7651	.0740	.101	.7845	.5770	.077	.7321	.2444	.433
.7664	.0774	.112	.7860	.5806	.085	.7375	.2577	.401
.7727	.0927	.168	.7875	.5843	.102	.7389	.2611	.407
.7740	.0958	.173	.7889	.5877	.120	.7404	.2648	.403
.7755	.0995	.199	.7942	.6007	.166	.7418	.2682	.403
.7769	.1029	.202	.7956	.6041	.193			

TABLE III. Normal points of V839 Ophiuchi

Yellow			Yellow			Blue		
Phase	Δm	n	Phase	Δm	n	Phase	Δm	n
.0119	+.563	9	.6642	+.079	7	.2658	+.019	10
.0381	.501	5	.7080	.033	6	.2900	.029	5
.0541	.417	5	.7446	.000	6	.3240	.065	5
.0673	.360	5	.7804	.002	7	.3464	.095	7
.0777	.308	7	.8053	.013	6	.3690	.147	6
.0937	.257	7	.8329	.063	6	.3889	.199	5
.1043	.205	7	.8695	.141	6	.4074	.269	6
.1193	.180	7	.9163	.291	7	.4302	.343	6
.1434	.117	8	.9306	.357	6	.4512	.466	6
.1667	.074	8	.9429	.406	7	.4620	.513	6
.1871	.047	8	.9606	.492	7	.4781	.553	9
.2114	.012	10	.9735	.542	8	.4989	.577	8
.2372	.006	10	.9899	.566	8	.5215	.563	6
.2642	.011	10				.5536	.449	6
.2880	.019	5				.5684	.376	7
.3219	.058	5				.5829	.319	7
.3444	.082	7				.5995	.245	7
.3673	.137	6				.6154	.196	7
.3869	.183	5				.6314	.156	8
.4054	.245	6				.6654	.082	8
.4285	.329	6				.7097	.023	6
.4491	.435	6				.7463	.000	6
.4602	.486	7				.7822	.005	8
.4765	.536	8				.8076	.027	7
.4982	.558	6				.8345	.061	6
.5207	.546	7				.8711	.150	6
.5514	.445	7				.9162	.305	8
.5667	.371	7				.9323	.381	6
.5813	.312	7				.9448	.423	7
.5978	.241	7				.9623	.523	7
.6139	.196	7				.9752	.564	8
.6297	.157	8				.9913	.593	9

Blue		
Phase	Δm	n
.0135	+.586	7
.0398	.499	5
.0572	.408	6
.0689	.361	5
.0778	.310	4
.0954	.259	7
.1059	.203	7
.1220	.181	8
.1451	.112	8
.1686	.064	8
.1889	.030	8
.2138	.006	9
.2389	.000	10

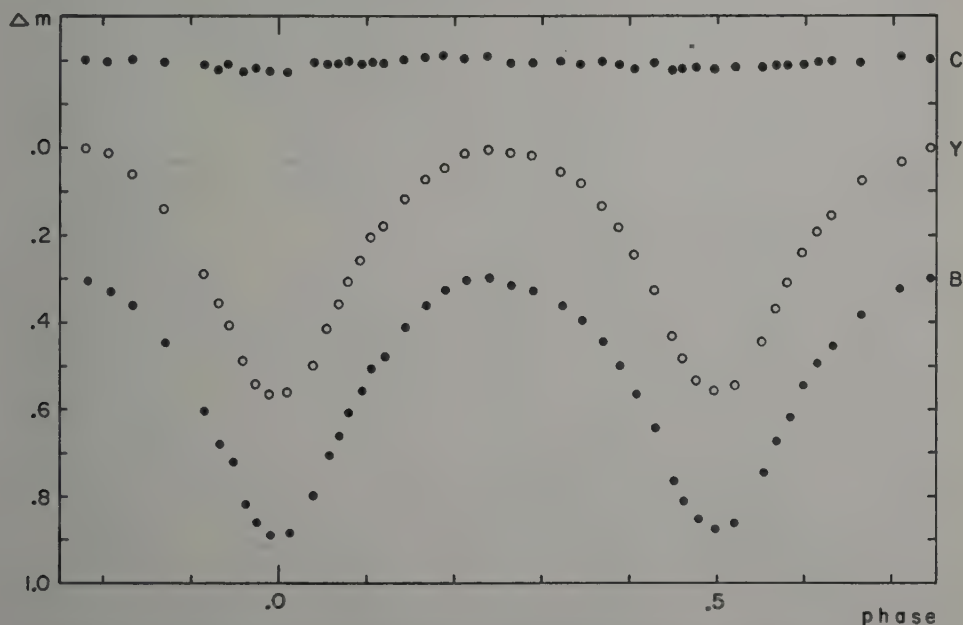


FIG. 1. The light curves and color curve of V839 Ophiuchi. The observations are B = blue, Y = yellow, C = color.

Photoelectric Observations of β Lyrae

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In connection with the international observing program of β Lyrae, photoelectric observations were made during six nights in three or four wavelengths with the 28-inch reflecting telescope at the Flower and Cook Observatory. Additional observations were made with the 15-inch siderostat.

THE international observing program of β Lyrae extended from August 8 to September 11, 1959. With fifteen observatories at different longitudes participating, the photometric coverage of the variable was very good, and during every 24-hour period photoelectric observations were made at between three and ten observatories.

During the summer the humidity in Philadelphia is usually very high; consequently the transparency is bad. During six nights photoelectric observations were

(1958) was used to compute phases:

$$\text{Min. } I = 2437349.4736 + 12.931163 E.$$

Table II(a, b, c, d, e) gives the heliocentric Julian Day, the phases counted from primary minimum, and the magnitude difference $\Delta m = m_{\beta} - m_{\gamma}$. In the first columns of Table III the normal points are given in this natural system.

Additional photoelectric observations in the yellow wavelength region were made by Mrs. Beverly B. Bookmyer who used the 15-inch siderostat and the Pierce pulse-counting photometer. These observations were reduced to the natural system of the 28-inch reflecting telescope and were added to both tables.

A dozen Praesepe stars of different magnitudes and colors were observed on March 10, and again on March 23, 1958 with the same 28-inch telescope, color filters, and photocell. These magnitudes and colors were reduced to outside atmosphere and least squares solutions were made to derive the conversion formulas between our natural system and the U, B, V system of H. L. Johnson (1952), for which the effective wavelengths are 3540 Å, 4360 Å, and 5460 Å, respectively.

We will call the color difference in our natural system,

$$\Delta C = C_{\beta} - C_{\gamma} = \Delta m_{4420} - \Delta m_{5300},$$

where $\Delta C = 0.85 \Delta(B - V)$. These conversion formulas can then be written for this case in the following form:

$$\Delta m_{5460} = 0.994 \Delta m_{5300} - 0.076 \Delta C$$

$$\Delta m_{4360} = 0.994 \Delta m_{4420} + 0.104 \Delta C$$

$$\Delta m_{3540} = 1.010 \Delta m_{3520} - 0.001 \Delta C.$$

The mean value of the probable errors is ± 0.003 for the scale factors and ± 0.007 for the color coefficients.

If we introduce Johnson's magnitudes of γ Lyrae as the zero points and interpolate the value for the violet magnitude, we find

$$m_{5460} = 3.23 + 1.070 \Delta m_{5300} - 0.076 \Delta m_{4420}$$

$$m_{4360} = 3.18 + 1.098 \Delta m_{4420} - 0.104 \Delta m_{5300}$$

$$m_{4200} = 3.17 + \Delta m_{4200}$$

$$m_{3540} = 3.08 + 1.010 \Delta m_{3520}.$$

In the last column of Table III these apparent magnitudes are given.

REFERENCES

- Johnson, H. L. 1952, *Astrophys. J.* **116**, 640.
Johnson, H. L. and W. W. Morgan 1953, *Astrophys. J.* **117**, 313.
Latko, A. 1958, *Rocznik Astron. Obs. Krakow* No. 29, 110.

TABLE I. Variable and comparison stars.

Star	R.A. (1900)	D. (1900)	m_{vis}	Sp.
β Lyrae	18 ^h 46 ^m 23 ^s	+33°14'8"	3.4-4.3	Bp
γ Lyrae	18 55 12	+32 31.8	3.23	B9 III
9 Lyrae	18 46 09	+32 26.1	5.19	A2

made in three or four wavelengths with the 28-inch reflecting telescope at the Flower and Cook Observatory, but only one night (JD 2436806) was an excellent one for photometry.

Table I gives the positions of the stars, the visual magnitudes, and the spectral types. The star γ Lyrae was chosen as the comparison star because this star has been included in the list of H. L. Johnson and W. W. Morgan (1953) and the magnitude and color differences with the variable are reasonably small.

The observations were made with a 1P21 photomultiplier. The output of this cell was fed into a direct current amplifier and the amplified current was recorded by a Brown recorder. The duration of each deflection was one minute. The effective wavelengths were 5300 Å (yellow), 4420 Å (blue), 4200 Å (violet), and 3520 Å (ultraviolet).

During four nights, the extinction coefficients could be determined from the observations of the comparison star; for the other two nights the extinction gradually increased. The magnitude difference between comparison and check star (9 Lyrae) remained constant after correction for differential extinction. The correction for relative extinction was then applied to the difference in magnitude between variable and comparison star. The observations were thus reduced to outside atmosphere.

The following ephemeris predicted by A. Latko

TABLE IIa. Observations of β Lyrae, yellow (5300 Å).

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6796.5771	.2431	+0.138	6806.6999	.0259	+1.048	6818.5987	.9461	+0.782
.5794	.2433	0.143	.7021	.0261	1.035	.6223	.9479	0.824
.5948	.2445	0.159	.7235	.0277	1.042	.6244	.9481	0.816
.5971	.2446	0.149	.7257	.0279	1.040	.6320	.9487	0.821
.6279	.2470	0.134	.7381	.0289	1.040	.6341	.9488	0.820
.6308	.2472	0.143	.7397	.0290	1.041	.6445	.9496	0.833
.6400	.2480	0.144	.7471	.0296	1.064	.6466	.9498	0.827
.6419	.2481	0.146	.7493	.0297	1.066	.6550	.9504	0.834
.6518	.2489	0.132	.7569	.0303	1.089	.6570	.9506	0.833
.6537	.2490	0.132	.7596	.0305	1.039	.6667	.9513	0.847
.6614	.2496	0.138	6807.5610	.0925	0.475	.6696	.9516	0.871
.6636	.2498	0.133	.5634	.0927	0.463	.6772	.9522	0.884
.6711	.2504	0.138	.5714	.0933	0.458	.6809	.9524	0.848
.6732	.2505	0.128	.5735	.0934	0.467	.6883	.9530	0.848
6800.6315	.5566	0.402	.6076	.0961	0.470	.6904	.9532	0.827
.6336	.5568	0.399	.6096	.0963	0.442	.7008	.9540	0.855
.6410	.5574	0.407	.6200	.0971	0.436	.7030	.9542	0.855
.6432	.5575	0.398	.6226	.0973	0.430	6823.5700	.3305	0.229
.7070	.5625	0.435	.6354	.0983	0.401	.5721	.3307	0.241
.7093	.5626	0.411	.6375	.0984	0.400	.5797	.3313	0.265
6806.5930	.0176	1.091	6818.5689	.9438	0.763	.5818	.3314	0.260
.5953	.0178	1.075	.5709	.9439	0.769	.6182	.3343	0.242
.6270	.0203	1.088	.5820	.9448	0.730	.6204	.3344	0.249
.6624	.0230	1.073	.5841	.9450	0.749	.6376	.3358	0.245
.6645	.0232	1.068	.5870	.9452	0.758	.6407	.3360	0.242
.6902	.0252	1.053	.5890	.9453	0.782	.6492	.3366	0.234
.6924	.0253	1.044	.5967	.9459	0.791	.6513	.3368	0.204

TABLE IIb. Observations of β Lyrae, blue (4420 Å).

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6796.5778	.2431	+0.180	6806.6931	.0254	+1.170	6818.6230	.9480	+0.908
.5804	.2434	0.189	.7006	.0260	1.141	.6251	.9481	0.903
.5954	.2445	0.187	.7027	.0261	1.139	.6327	.9487	0.908
.5981	.2447	0.180	.7242	.0278	1.171	.6348	.9489	0.911
.6289	.2471	0.171	.7263	.0280	1.147	.6452	.9497	0.932
.6315	.2473	0.191	.7388	.0289	1.147	.6473	.9498	0.941
.6406	.2480	0.184	.7404	.0291	1.156	.6556	.9505	0.920
.6426	.2482	0.203	.7480	.0296	1.191	.6577	.9506	0.928
.6524	.2489	0.179	.7500	.0298	1.184	.6673	.9514	0.925
.6544	.2491	0.178	.7576	.0304	1.170	.6702	.9516	0.925
.6621	.2497	0.183	.7602	.0306	1.145	.6779	.9522	0.938
.6643	.2498	0.188	6807.5618	.0926	0.553	.6816	.9525	0.946
.6718	.2504	0.170	.5641	.0927	0.541	.6890	.9531	0.925
.6740	.2506	0.171	.5721	.0934	0.539	.6912	.9532	0.898
6800.6322	.5567	0.444	.5743	.0935	0.540	.7015	.9540	0.972
.6343	.5568	0.451	.6082	.0962	0.535	.7036	.9542	0.975
.6418	.5574	0.449	.6103	.0963	0.516	6823.5707	.3306	0.272
.6439	.5576	0.451	.6207	.0971	0.505	.5728	.3307	0.295
.7077	.5625	0.463	.6233	.0973	0.499	.5804	.3313	0.290
.7099	.5627	0.445	.6360	.0983	0.466	.5825	.3315	0.316
6806.5938	.0177	1.188	.6382	.0985	0.454	.6188	.3343	0.290
.5961	.0179	1.187	6818.5695	.9438	0.830	.6210	.3345	0.308
.6277	.0203	1.213	.5716	.9440	0.852	.6384	.3358	0.286
.6296	.0205	1.187	.5849	.9450	0.803	.6415	.3361	0.308
.6631	.0231	1.182	.5876	.9452	0.830	.6499	.3367	0.266
.6652	.0232	1.191	.5897	.9454	0.873	.6519	.3369	0.252
.6909	.0252	1.158	.5973	.9460	0.916			

TABLE IIc. Observations of β Lyrae, violet (4200 Å).

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6796.5786	.2432	+0.161	6806.6916	.0253	+1.125	6818.6334	.9488	+0.897
.5813	.2434	0.168	.6938	.0255	1.145	.6355	.9489	0.908
.5963	.2446	0.156	.7014	.0260	1.161	.6459	.9497	0.928
.5989	.2448	0.156	.7035	.0262	1.148	.6480	.9499	0.925
.6294	.2472	0.191	.7249	.0279	1.166	.6563	.9505	0.908
.6322	.2474	0.162	.7270	.0280	1.163	.6584	.9507	0.919
.6412	.2480	0.158	.7412	.0291	1.164	.6680	.9514	0.919
.6433	.2482	0.164	.7486	.0297	1.173	.6709	.9517	0.906
.6530	.2490	0.156	.7507	.0298	1.184	.6800	.9524	0.923
.6551	.2491	0.151	.7584	.0304	1.203	.6820	.9525	0.937
.6628	.2497	0.149	.7614	.0307	1.173	.6897	.9531	0.921
.6648	.2499	0.157	6807.5626	.0926	0.535	.6919	.9533	0.907
.6725	.2505	0.158	.5649	.0928	0.524	.7022	.9541	0.943
6800.6328	.5567	0.421	.5728	.0934	0.534	.7044	.9543	0.939
.6349	.5569	0.412	.5750	.0936	0.529	6823.5714	.3306	0.266
.6426	.5575	0.417	.6089	.0962	0.506	.5736	.3308	0.277
.6447	.5577	0.430	.6110	.0964	0.489	.5811	.3314	0.268
.7085	.5626	0.420	.6214	.0972	0.483	.5832	.3315	0.270
.7106	.5627	0.411	.6241	.0974	0.478	.6195	.3344	0.273
6806.5945	.0178	1.183	.6368	.0984	0.448	.6221	.3346	0.281
.5967	.0179	1.186	.6388	.0985	0.451	.6399	.3359	0.281
.6285	.0204	1.186	6818.5702	.9439	0.803	.6423	.3361	0.259
.6304	.0205	1.180	.5723	.9440	0.830	.6506	.3368	0.232
.6638	.0232	1.171	.6237	.9480	0.886	.6526	.3369	0.248
.6659	.0233	1.176	.6258	.9482	0.889			

TABLE IIId. Observations of β Lyrae, ultraviolet (3520 Å).

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6796.6100	.2456	-0.331	6806.6145	.0193	+ .758	6807.5874	.0946	+0.063
.6164	.2461	0.336	.6177	.0195	.774	.5889	.0947	0.047
.6169	.2462	0.356	.6187	.0196	.767	.5896	.0947	0.110
.6177	.2462	0.341	.6756	.0240	.750	.5902	.0948	0.093
6800.6821	.5605	0.046	.6770	.0241	.766	6823.5944	.3324	-0.207
.6828	.5606	0.013	.7136	.0270	.739	.5951	.3325	0.206
.6864	.5609	0.028	.7143	.0270	.731	.5985	.3327	0.198
.6871	.5609	0.034	.7150	.0271	.729	.5992	.3328	0.198
6806.6130	.0192	+0.767	6807.5867	.0945	.095	.5999	.3328	0.189

TABLE IIe. Observations made with 15-inch siderostat, yellow.

JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm	JD Hel. 2430000+	Phase	Δm
6806.5991	.0181	+1.079	6818.5710	.9439	+0.737	6806.6926	.9533	+0.824
.6167	.0195	1.066	.5864	.9451	0.730	6823.5780	.3311	0.259
.6242	.0200	1.065	.5956	.9458	0.750	.5881	.3320	0.202
.6321	.0207	1.093	.6044	.9465	0.769	.5952	.3325	0.215
.6414	.0214	1.083	.6112	.9471	0.784	.6004	.3328	0.235
.6637	.0231	1.096	.6200	.9478	0.782	.6080	.3335	0.231
.6727	.0238	1.061	6806.6308	.9485	0.824	.6140	.3339	0.214
.6785	.0242	1.047	.6431	.9495	0.859	.6404	.3360	0.261
.6881	.0250	1.066	.6604	.9508	0.835	.6448	.3363	0.232
.6937	.0254	1.042	.6720	.9517	0.877	.6512	.3371	0.242
.7013	.0260	1.045	.6820	.9525	0.836	.6572	.3376	0.263
			.6864	.9529	0.856			

TABLE III. Normal points.

JD Hel. 2430000+	Phase	Yellow Δm_{6800}	n	Visual m_{5460}	JD Hel. 2430000+	Phase	Violet Δm_{4200}	n	Violet m_{4200}
6796.6066	.2454	+0.144	7	3.37	6796.6028	.2451	+0.166	6	3.34
.6596	.2495	0.135	7	3.36	.6561	.2492	0.156	7	3.33
6800.6609	.5589	0.409	6	3.63	6800.6623	.5590	0.419	6	3.59
6806.6284	.0203	1.079	5	4.29	6806.6228	.0200	1.181	5	4.35
.7056	.0264	1.044	6	4.26	.6969	.0258	1.154	6	4.32
.7484	.0297	1.056	6	4.27	.7479	.0296	1.177	6	4.35
6807.5754	.0936	0.467	5	3.69	6807.5768	.0937	0.526	5	3.70
.6250	.0975	0.422	5	3.64	.6264	.0976	0.470	5	3.64
6818.5803	.9447	0.759	6	3.98	6818.6101	.9470	0.869	6	4.04
.6180	.9476	0.809	6	4.03	.6579	.9506	0.917	6	4.09
.6566	.9505	0.841	6	4.06	.6917	.9533	0.928	6	4.10
.6901	.9532	0.853	6	4.07	6823.5859	.3317	0.271	5	3.44
6823.5844	.3316	0.247	5	3.47	.6415	.3360	0.260	5	3.43
.6398	.3359	0.234	5	3.46					
JD Hel. 2430000+	Phase	Blue Δm_{4420}	n	Blue m_{4380}	JD Hel. 2430000+	Phase	Ultrav. Δm_{3820}	n	Ultrav. m_{3540}
6796.6077	.2454	+0.183	7	3.37	6796.6152	.2460	-0.341	4	2.74
.6602	.2495	0.182	7	3.37	6800.6846	.5607	-0.030	4	3.05
6800.6616	.5590	0.450	6	3.63	6806.6160	.0194	+0.766	4	3.85
6806.6293	.0215	1.191	6	4.36	.6991	.0258	+0.743	5	3.83
.7063	.0264	1.154	6	4.34	6807.5886	.0947	+0.082	5	3.16
.7492	.0297	1.165	6	4.35					
6807.5761	.0937	0.542	5	3.73	Observations made with 15-inch siderostat				
.6257	.0975	0.488	5	3.67	JD Hel. 2430000+	Phase	Yellow Δm	n	Yellow m_{5460}
6818.5807	.9447	0.838	5	4.02	6806.6227	.0199	+1.077	5	4.29
.6226	.9480	0.909	5	4.09	.6830	.0246	1.060	6	4.28
.6572	.9506	0.929	6	4.11	6818.5981	.9460	0.759	6	3.98
.6908	.9532	0.942	6	4.12	.6668	.9513	0.844	7	4.06
6823.5850	.3317	0.293	5	3.48	6823.5973	.3326	0.226	6	3.45
.6405	.3360	0.284	5	3.47	.6484	.3367	0.249	4	3.47

The Light Variation and Orbital Elements of U Pegasi*

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Photoelectric observations are presented of 446 yellow and 441 blue magnitudes of U Pegasi made during seven nights in October and November, 1958. The light curve repeated itself during these two months in both wavelength regions, but showed a definite change when compared with LaFara's photoelectric observations made during the years 1949 and 1950. As a consequence, the coefficient of the $\sin \theta$ term changed considerably during these nine years. The primary eclipse is an occultation. New orbital elements derived are compared with orbital solutions found from older observations.

THE variable U Pegasi of the W Ursae Majoris type was discovered by S. C. Chandler (1895). By using the observations of O. C. Wendell (1909), the first orbital elements were derived by H. Shapley (1915). Later, the observations of J. Schilt (1924) were used by S. Gaposchkin (1932) to derive orbital elements. Further photographic observations were made by E. G. Jordan (1929), and by F. Recillas and E. J. Woodward (1945).

R. LaFara (1951) observed the system photoelectrically in two wavelength regions with the 36-inch reflecting telescope of the Goethe Link Observatory during the years 1949 and 1950. His light curves appear to be very accurate as is shown by the appearance of the color curve. These observations were used by Z. Kopal and M. B. Shapley (1956) to derive orbital elements. K. K. Kwee (1958) has published three times of minimum from photoelectric observations.

During the winters of 1951 and 1952-1953, M. Huruhata, M. Kitamura, and T. Nakamura (1952, 1957) observed the variable photoelectrically in three wavelength regions. Their observations were made with the 26-inch refracting telescope of the Tokyo Astronomical Observatory. The deflection lasted for only 10 sec, which is a rather short time interval, and the highest accuracy was not obtained. The most peculiar behavior was the flaring of the system in the maxima which was observed on two occasions to be as much as 0.3 magnitudes in the ultraviolet, and 0.1 magnitudes in the blue wavelength region. This flaring lasted about half an hour. It can be seen that the ultraviolet observations in the minima also show a large spread. Unfortunately no checks were made, or at least they were not mentioned, to prove that these changes were not instrumental in nature. In a refractor, the ultraviolet light is out of focus, so that occasionally the light beam of the variable or of the comparison star could be partially intercepted by the diaphragm on a night of bad seeing. During one night no flaring at all was observed. A possible rotation of the line of apsides was discussed.

This system was observed photoelectrically in the

effective wavelengths 5300 Å and 4420 Å with the 28-inch reflecting telescope of the Flower and Cook Observatory during October and November, 1958. The observations were made with a 1P21 photomultiplier cell, the output of which was fed into a direct current amplifier newly built by Dr. W. M. Protheroe, and the amplified current was recorded by a Brown recorder. The duration of one deflection was one minute.

Table I gives the BD number, the position of the stars, and the spectrum of the variable according to O. Struve (1950) and collaborators, who gave the results of a few radial velocity data. The difference in magnitude between the comparison star and check star

TABLE I. Variable and Comparison Stars

Star	BD No.	R.A.(1900)	D.(1900)	Sp.
U Pegasi	+15°4915	23 ^h 52 ^m 52 ^s	+15°23' 8	F3
Comp. star	14 5078	23 52 39	14 54.9	F8
Check star	14 5080	23 54 44	15 13.8	...

was found to be constant. The extinction for each night was determined from the observations of the comparison star, and the correction for relative extinction was applied to the difference in magnitude between the variable and comparison stars.

Times of minima were determined according to Hertzsprung's method (1928). Six new values are given in Table II, together with the earlier data. It can be noted that there is a slight systematic difference in the $O-C$'s of our results, for the times of secondary minimum come 0.002 days later than expected. Figure 1 illustrates the change in period. Included here are estimates from Harvard plates as published by Recillas and Woodward. The linear ephemeris used was:

$$\text{Minimum I} = 2430260.6790 + 0.37478268E.$$

For our recent observations the period is slightly different, and the best value was:

$$\text{Minimum I} = 2436511.66878 + 0.37478192E.$$

Tables IIIa and IIIb give the observations in heliocentric Julian Day, phase counted from primary

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TABLE II. Times of Minima of U Pegasi

J. D. $\odot$	Min.	O-C	Meth.	Obs. ^a	Ref.
2413514.619	I	-0.028	v	Ch	1, 2
3542.531	II	-0.030	v	Ye	3
3830.561	I	-0.020	v	Ye	4
4907.682	I	-0.024	v	Ye	4
5021.237	I	-0.029	v	We	5, 6
2420072.594	I	+0.007	v	Sh	7
0756.751	II	-0.001	pg	Jo	8, 9
1130.598	I	0.000	pg	Jo	8, 9
3735.340	I	+0.002	pg	Sc	10
7744.393	I	+0.005	v	La	11
8521.321	I	+0.008	v	La	12
9522.736	I	+0.004	pg	R, W	9
2430260.679	I	+0.004	pg	R, W	9
0260.866	II	0.000	pg	R, W	9
3182.8561	I	-0.0034	pe	LF	13
3190.7262	I	0.0038	pe	LF	13
3190.9132	II	0.0042	pe	LF	13
3202.7181	I	0.0050	pe	LF	13
3230.6408	II	0.0036	pe	LF	13
3244.5075	II	0.0038	pe	LF	13
3255.5630	I	0.0044	pe	LF	13
3558.7624	I	0.0042	pe	LF	13
3561.7592	I	0.0056	pe	LF	13
3924.54967	I	0.0048	pe	Kw	14
3998.9448	II	0.0040	pe	H, K, N	15
4303.45450	I	0.0053	pe	Kw	14
4685.35860	I	0.0047	pe	Kw	14
6481.68639	I	0.0103	pe	Bi	...
6483.74902	II	0.0090	pe	Bi	...
6484.68389	I	0.0111	pe	Bi	...
6508.67015	I	0.0109	pe	Bi	...
6511.66878	I	0.0105	pe	Bi	...
6515.60569	II	-0.0089	pe	Bi	...

^a Ch=Chandler 1 (1895), 2 (1896); Ye=Yendell 3 (1896), 4 (1900); We=Wendell 5 (1909); Roberts 6 (1906); Sh=Shapley 7 (1915); Jo=Jordan 8 (1929); R, W=Recillas and Woodward 9 (1945); Sc=Schildt 10 (1924, 1925); La=Lause 11 (1935), 12 (1937); LF=LaFara 13 (1951); Kw=Kwee 14 (1958); H, K, N=Huruhata, Kitamura, and Nakamura 15 (1957); Bi=Binnendijk.

minimum, and the magnitude difference in the sense variable minus comparison star. A total of 446 yellow and 441 blue magnitudes were obtained during seven nights. The observations during the four nights in October were combined into normal points, and the same was done for the observations during the three nights in November. The largest deviation between normals at the same phase was less than 0.01 magnitude, so that the light curve repeated itself in both wavelength regions. During this time no trace of flaring was found which would have been discovered readily in the blue wavelength.

Table IV and Fig. 2 show the normal points of the observations of all seven nights. A zero point correction of +0.012 for the yellow magnitudes and -0.032 for the blue magnitudes was applied to make the magnitude difference equal to zero at maximum. The probable error for a normal point consisting of nine observations was found to be ± 0.0014 magnitudes. These normal points were compared with LaFara's normal points of the years 1949 and 1950. A zero point correction was applied, but the scale was not altered. The primary minimum and the following maximum could be made to coincide perfectly, but the secondary minimum and following maximum are brighter in his light curves (between phases 0.33 and 0.90). There is certainly a change in the light curves in nine years' time as is seen in Fig. 3. The largest difference amounts to 0.05 magnitudes.

The magnitudes and phases of LaFara's, and of our normal points were converted into intensities and phase

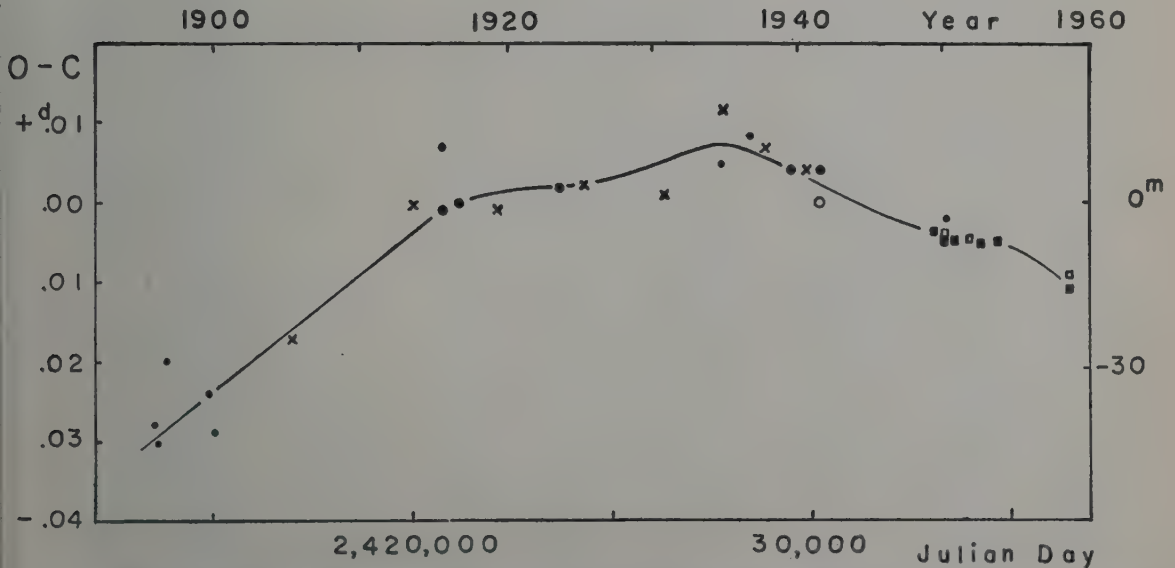


FIG. 1. Period variation of U Pegasi. Visual observations are small dots, photographic observations are large dots, estimates on Harvard plates are crosses, photoelectric data are squares. Open symbols refer to the secondary minimum.

TABLE III a. Yellow Observations of U Pegasi.

JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm
6481.6491	0.9008	+0.187	6483.6446	0.2255	+0.006	6484.6312	0.8578	+0.101
.6507	0.9052	0.205	.6465	0.2304	-0.004	.6326	0.8615	0.112
.6518	0.9083	0.220	.6479	0.2341	+0.001	.6382	0.8764	0.135
.6532	0.9120	0.240	.6541	0.2508	-0.022	.6395	0.8801	0.152
.6601	0.9302	0.301	.6555	0.2545	-0.019	.6409	0.8838	0.158
.6616	0.9342	0.313	.6570	0.2585	-0.022	.6423	0.8875	0.160
.6630	0.9379	0.323	.6586	0.2628	-0.014	.6483	0.9035	0.208
.6643	0.9416	0.340	.6678	0.2872	-0.017	.6496	0.9069	0.217
.6657	0.9453	0.372	.6704	0.2943	-0.013	.6511	0.9109	0.227
.6713	0.9602	0.468	.6720	0.2984	-0.010	.6525	0.9146	0.247
.6726	0.9635	0.489	.6733	0.3021	-0.005	.6581	0.9295	0.318
.6741	0.9675	0.502	.6845	0.3317	+0.044	.6593	0.9329	0.325
.6755	0.9713	0.512	.6858	0.3354	0.042	.6608	0.9369	0.348
.6809	0.9858	0.549	.6872	0.3391	0.046	.6621	0.9403	0.368
.6824	0.9898	0.555	.6888	0.3434	0.038	.6678	0.9554	0.450
.6838	0.9935	0.566	.6946	0.3589	0.084	.6691	0.9588	0.472
.6852	0.9972	0.572	.6963	0.3632	0.082	.6706	0.9629	0.472
.6906	0.0117	0.566	.6976	0.3669	0.090	.6719	0.9665	0.487
.6921	0.0157	0.543	.7044	0.3848	0.134	.6775	0.9814	0.539
.6935	0.0194	0.552	.7060	0.3891	0.137	.6788	0.9848	0.548
.6948	0.0228	0.537	.7075	0.3931	0.145	.6803	0.9888	0.542
.7007	0.0386	0.458	.7088	0.3966	0.155	.6816	0.9922	0.563
.7024	0.0432	0.420	.7148	0.4126	0.216	.6871	0.0070	0.560
.7038	0.0469	0.415	.7163	0.4166	0.223	.6885	0.0107	0.542
.7052	0.0506	0.397	.7182	0.4219	0.244	.6900	0.0147	0.545
.7109	0.0657	0.341	.7202	0.4271	0.258	.6914	0.0184	0.542
.7123	0.0695	0.330	.7264	0.4435	0.332	.6968	0.0329	0.492
.7135	0.0728	0.312	.7280	0.4478	0.350	.6982	0.0366	0.465
.7150	0.0769	0.291	.7295	0.4518	0.377	.6997	0.0407	0.463
.7206	0.0917	0.230	.7309	0.4555	0.385	.7010	0.0441	0.422
.7220	0.0954	0.205	.7406	0.4815	0.490	.7065	0.0589	0.354
.7234	0.0991	0.182	.7421	0.4855	0.497	.7079	0.0626	0.324
.7248	0.1028	0.182	.7435	0.4892	0.510	.7094	0.0666	0.317
.7317	0.1213	0.156	.7449	0.4929	0.517	.7108	0.0703	0.303
.7331	0.1250	0.153	.7514	0.5102	0.515	.7163	0.0848	0.241
.7345	0.1287	0.129	.7527	0.5139	0.523	.7177	0.0885	0.219
.7359	0.1325	0.123	.7542	0.5179	0.504	.7192	0.0925	0.203
.7421	0.1491	0.107	.7559	0.5223	0.481	.7205	0.0962	0.193
.7435	0.1528	0.086	.7614	0.5371	0.437	6508.5030	0.5531	+0.374
.7449	0.1565	0.076	.7629	0.5411	0.424	.5044	0.5568	0.354
.7463	0.1603	0.066	.7645	0.5454	0.411	.5058	0.5605	0.337
.7472	0.1627	0.070	.7662	0.5497	0.386	.5072	0.5642	0.319
6483.5553	0.9871	+0.573	.7725	0.5667	0.333	.5128	0.5791	0.279
.5567	0.9908	0.557	.7739	0.5704	0.312	.5141	0.5828	0.267
.5590	0.9970	0.585	.7754	0.5744	0.300	.5155	0.5865	0.243
.5604	0.0006	0.581	.7768	0.5781	0.290	.5169	0.5902	0.238
.5663	0.0164	0.543	.7829	0.5945	0.218	.5225	0.6050	0.185
.5685	0.0222	0.529	.7845	0.5985	0.213	.5239	0.6087	0.174
.5699	0.0260	0.544	.7858	0.6022	0.194	.5253	0.6124	0.165
.5775	0.0463	0.424	.7872	0.6060	0.186	.5266	0.6161	0.156
.5789	0.0500	0.403	.7928	0.6208	0.139	.5322	0.6310	0.123
.5804	0.0541	0.391	.7942	0.6245	0.130	.5336	0.6347	0.113
.5817	0.0575	0.367	.7956	0.6282	0.122	.5350	0.6383	0.104
.5872	0.0723	0.303	.7970	0.6319	0.125	.5364	0.6421	0.101
.5886	0.0760	0.293	6484.5798	0.7207	+0.006	.5419	0.6569	0.092
.5901	0.0800	0.287	.5826	0.7281	0.003	.5433	0.6606	0.077
.5917	0.0843	0.260	.5842	0.7325	0.014	.5447	0.6643	0.071
.5971	0.0985	0.208	.5905	0.7491	0.008	.5461	0.6680	0.066
.6025	0.1131	0.160	.5920	0.7531	0.009	.5516	0.6828	0.053
.6039	0.1168	0.169	.5935	0.7572	0.016	.5530	0.6865	0.048
.6054	0.1208	0.147	.5949	0.7609	0.024	.5545	0.6905	0.046
.6067	0.1242	0.134	.6006	0.7763	0.017	.5558	0.6940	0.056
.6194	0.1581	0.075	.6020	0.7800	0.015	.5614	0.7088	0.031
.6206	0.1612	0.071	.6034	0.7837	0.018	.5628	0.7125	0.028
.6221	0.1652	0.056	.6048	0.7874	0.019	.5640	0.7159	0.019
.6237	0.1696	0.053	.6104	0.8023	0.031	.5655	0.7199	0.019
.6318	0.1912	0.021	.6120	0.8065	0.034	.5711	0.7347	0.013
.6333	0.1952	0.017	.6134	0.8103	0.041	.5725	0.7384	0.016
.6347	0.1989	0.017	.6148	0.8140	0.058	.5739	0.7421	0.010
.6361	0.2026	0.018	.6284	0.8504	0.103	.5753	0.7458	0.007
.6431	0.2215	0.003	.6298	0.8541	0.093	.5939	0.7956	0.016

TABLE III a.—*Continued.*

JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm
6508.5954	0.7996	+0.021	6511.5736	0.7460	+0.016	6515.5978	0.4834	+0.479
.5967	0.8030	0.035	.5751	0.7500	0.015	.5992	0.4871	0.493
.5982	0.8070	0.039	.5765	0.7537	0.016	.6005	0.4908	0.509
.6092	0.8363	0.091	.5779	0.7575	0.017	.6060	0.5053	0.510
.6107	0.8403	0.088	.5834	0.7723	0.018	.6075	0.5094	0.509
.6121	0.8440	0.096	.5848	0.7760	0.016	.6089	0.5131	0.504
.6135	0.8477	0.098	.5862	0.7797	0.019	.6103	0.5167	0.512
.6189	0.8623	0.112	.5876	0.7834	0.010	.6164	0.5331	0.466
.6204	0.8663	0.109	.5932	0.7982	0.031	.6179	0.5371	0.435
.6218	0.8700	0.125	.5945	0.8019	0.035	.6193	0.5408	0.424
.6232	0.8737	0.125	.5958	0.8053	0.039	.6207	0.5446	0.420
.6286	0.8882	0.174	.5973	0.8093	0.043	.6262	0.5594	0.349
.6301	0.8922	0.179	.6028	0.8238	0.075	.6276	0.5631	0.337
.6315	0.8959	0.187	.6043	0.8279	0.074	.6290	0.5668	0.313
.6329	0.8996	0.194	.6055	0.8313	0.071	.6304	0.5705	0.300
.6418	0.9234	0.287	.6127	0.8504	0.093	.6360	0.5853	0.254
.6432	0.9271	0.287	.6142	0.8544	0.100	.6374	0.5890	0.237
.6446	0.9308	0.311	.6155	0.8578	0.109	.6387	0.5927	0.234
.6461	0.9348	0.326	.6170	0.8618	0.116	.6401	0.5965	0.209
.6516	0.9496	0.413	.6223	0.8760	0.129	.6456	0.6110	0.176
.6529	0.9531	0.427	.6237	0.8797	0.141	.6471	0.6150	0.169
.6544	0.9571	0.442	.6251	0.8834	0.156	.6483	0.6184	0.162
.6558	0.9608	0.464	.6265	0.8872	0.164	.6499	0.6224	0.141
.6613	0.9753	0.528	.6320	0.9020	0.212	.6554	0.6372	0.120
.6628	0.9793	0.530	.6334	0.9057	0.225	.6568	0.6409	0.107
.6641	0.9830	0.532	.6348	0.9094	0.238	.6582	0.6446	0.103
.6655	0.9867	0.547	.6362	0.9131	0.251	.6596	0.6483	0.103
.6710	0.0012	0.550	.6418	0.9279	0.297	.6650	0.6628	0.081
.6725	0.0053	0.547	.6432	0.9316	0.322	.6666	0.6672	0.068
.6739	0.0090	0.546	.6445	0.9353	0.335	.6679	0.6705	0.065
.6752	0.0124	0.532	.6458	0.9387	0.351	.6693	0.6743	0.053
.6807	0.0272	0.499	.6529	0.9576	0.433	.6907	0.7314	0.024
.6822	0.0312	0.487	.6541	0.9610	0.451	.6922	0.7354	0.014
.6836	0.0349	0.463	.6557	0.9650	0.467	.6936	0.7391	0.019
.6850	0.0386	0.452	.6569	0.9683	0.496	.6950	0.7428	0.014
.6919	0.0571	0.373	.6627	0.9838	0.562	.7012	0.7595	0.007
.6932	0.0605	0.355	.6642	0.9878	0.561	.7026	0.7632	0.007
.6947	0.0645	0.331	.6656	0.9915	0.567	.7040	0.7669	0.001
.6961	0.0683	0.307	.6670	0.9952	0.569	.7055	0.7709	0.000
.7029	0.0865	0.235	.6725	0.0100	0.561	6519.5649	0.0685	+0.330
.7044	0.0905	0.212	.6739	0.0138	0.558	.5663	0.0722	0.308
.7058	0.0942	0.193	.6753	0.0175	0.544	.5676	0.0759	0.299
.7072	0.0979	0.185	.6766	0.0209	0.537	.5693	0.0802	0.279
.7126	0.1124	0.153	.6831	0.0382	0.472	.5753	0.0963	0.222
.7140	0.1161	0.135	.6845	0.0419	0.442	.5766	0.0997	0.199
.7154	0.1198	0.125	.6859	0.0456	0.433	.5781	0.1037	0.188
.7169	0.1238	0.134	.6874	0.0496	0.414	.5793	0.1071	0.165
6511.5062	0.5663	+0.318	.6940	0.0672	0.333	.5850	0.1223	0.140
.5083	0.5718	0.294	.6955	0.0712	0.314	.5864	0.1259	0.126
.5091	0.5740	0.288	.6969	0.0749	0.297	.5878	0.1296	0.116
.5105	0.5777	0.274	.7046	0.0956	0.203	.5892	0.1334	0.108
.5161	0.5925	0.222	.7062	0.0999	0.175	.5961	0.1519	0.087
.5175	0.5962	0.212	.7077	0.1040	0.178	.5975	0.1556	0.082
.5188	0.5999	0.198	.7091	0.1076	0.151	.5989	0.1593	0.069
.5202	0.6037	0.181	.7147	0.1225	0.139	.6002	0.1627	0.065
.5265	0.6203	0.143	.7161	0.1262	0.132	.6058	0.1778	0.036
.5279	0.6240	0.135	.7175	0.1299	0.120	.6071	0.1812	0.024
.5293	0.6278	0.127	.7188	0.1336	0.107	.6086	0.1853	0.025
.5307	0.6315	0.122	6515.5622	0.3886	+0.138	.6099	0.1886	0.018
.5362	0.6463	0.108	.5637	0.3926	0.143	.6156	0.2038	0.012
.5383	0.6518	0.112	.5651	0.3963	0.150	.6170	0.2075	0.010
.5397	0.6555	0.098	.5664	0.3997	0.166	.6183	0.2112	0.004
.5411	0.6592	0.095	.5721	0.4149	0.226	.6196	0.2146	0.010
.5465	0.6738	0.060	.5735	0.4186	0.226	.6308	0.2445	-0.020
.5479	0.6775	0.055	.5747	0.4220	0.246	.6321	0.2479	-0.015
.5494	0.6815	0.054	.5761	0.4257	0.266	.6335	0.2516	-0.018
.5508	0.6852	0.046	.5858	0.4516	0.366	.6350	0.2556	-0.012
.5563	0.7000	0.035	.5874	0.4556	0.384	.6413	0.2723	-0.002
.5577	0.7037	0.037	.5886	0.4590	0.401	.6425	0.2757	0.000
.5591	0.7074	0.020	.5901	0.4630	0.410	.6439	0.2794	-0.002
.5606	0.7114	0.027	.5963	0.4794	0.467	.6453	0.2831	-0.002

TABLE III a.—*Continued.*

JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm
6519.6571	0.3146	+0.003	6519.6710	0.3517	+0.057	6519.6892	0.4002	+0.167
.6585	0.3183	0.007	.6767	0.3668	0.079	.6905	0.4036	0.177
.6600	0.3223	0.019	.6780	0.3702	0.090	.6961	0.4187	0.224
.6613	0.3258	0.027	.6795	0.3742	0.094	.6974	0.4221	0.238
.6670	0.3409	0.036	.6808	0.3780	0.105	.6989	0.4261	0.266
.6683	0.3446	0.047	.6863	0.3925	0.150	.7003	0.4298	0.288
.6697	0.3483	0.050	.6877	0.3962	0.152			

TABLE IIIb. Blue Observations of U Pegasi

JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm
6481.6498	0.9027	+0.252	6483.6060	0.1223	+0.184	6483.7836	0.5964	+0.256
.6511	0.9064	0.252	.6073	0.1258	0.178	.7851	0.6004	0.256
.6524	0.9098	0.294	.6200	0.1597	0.112	.7864	0.6038	0.237
.6545	0.9154	0.314	.6213	0.1631	0.114	.7878	0.6075	0.228
.6608	0.9321	0.370	.6226	0.1668	0.105	.7935	0.6226	0.188
.6623	0.9361	0.387	.6245	0.1717	0.100	.7949	0.6263	0.188
.6636	0.9398	0.413	.6325	0.1930	0.065	.7963	0.6300	0.180
.6650	0.9435	0.426	.6339	0.1967	0.063	.7975	0.6334	0.169
.6663	0.9469	0.435	.6353	0.2005	0.050	6484.5805	0.7226	+0.044
.6719	0.9617	0.565	.6367	0.2042	0.065	.5819	0.7263	0.047
.6732	0.9654	0.569	.6439	0.2236	0.041	.5835	0.7306	0.055
.6746	0.9691	0.623	.6452	0.2270	0.042	.5911	0.7510	0.057
.6760	0.9728	0.617	.6472	0.2323	0.021	.5928	0.7553	0.063
.6816	0.9875	0.650	.6485	0.2357	0.021	.5941	0.7587	0.063
.6830	0.9913	0.626	.6548	0.2526	0.030	.5954	0.7624	0.074
.6842	0.9947	0.640	.6562	0.2564	0.036	.6013	0.7782	0.065
.6857	0.9987	0.637	.6577	0.2604	0.026	.6027	0.7819	0.071
.6913	0.0136	0.626	.6593	0.2647	0.034	.6041	0.7856	0.071
.6927	0.0173	0.616	.6685	0.2891	0.029	.6055	0.7893	0.068
.6941	0.0210	0.611	.6713	0.2965	0.034	.6113	0.8047	0.086
.6955	0.0247	0.603	.6726	0.3002	0.034	.6127	0.8084	0.095
.7016	0.0410	0.494	.6740	0.3039	0.045	.6141	0.8121	0.097
.7031	0.0451	0.476	.6851	0.3336	0.090	.6153	0.8155	0.117
.7045	0.0488	0.469	.6864	0.3370	0.088	.6291	0.8523	0.154
.7059	0.0525	0.449	.6879	0.3410	0.095	.6305	0.8560	0.146
.7114	0.0673	0.406	.6895	0.3453	0.099	.6319	0.8597	0.167
.7130	0.0713	0.386	.6953	0.3607	0.133	.6333	0.8634	0.174
.7142	0.0747	0.358	.6969	0.3650	0.138	.6388	0.8782	0.198
.7156	0.0784	0.348	.6983	0.3687	0.148	.6402	0.8819	0.213
.7226	0.0969	0.252	.7049	0.3864	0.177	.6416	0.8856	0.222
.7241	0.1009	0.236	.7067	0.3910	0.193	.6430	0.8893	0.218
.7253	0.1044	0.230	.7079	0.3944	0.206	.6489	0.9051	0.270
.7324	0.1232	0.204	.7093	0.3981	0.227	.6504	0.9091	0.277
.7338	0.1269	0.184	.7154	0.4142	0.270	.6518	0.9128	0.296
.7351	0.1303	0.184	.7170	0.4185	0.276	.6531	0.9162	0.306
.7365	0.1340	0.169	.7189	0.4237	0.302	.6586	0.9310	0.384
.7427	0.1507	0.139	.7210	0.4293	0.322	.6600	0.9347	0.397
.7441	0.1544	0.124	.7272	0.4457	0.407	.6615	0.9387	0.417
.7455	0.1581	0.117	.7287	0.4497	0.426	.6628	0.9421	0.441
.7483	0.1655	0.103	.7300	0.4531	0.450	.6685	0.9573	0.533
6483.5559	0.9886	+0.637	.7317	0.4577	0.466	.6697	0.9607	0.556
.5574	0.9927	0.640	.7414	0.4836	0.571	.6711	0.9644	0.556
.5597	0.9988	0.664	.7427	0.4870	0.580	.6726	0.9684	0.572
.5611	0.0033	0.664	.7442	0.4911	0.588	.6781	0.9829	0.617
.5670	0.0182	0.599	.7454	0.4944	0.589	.6796	0.9869	0.644
.5691	0.0238	0.610	.7519	0.5118	0.592	.6809	0.9903	0.637
.5782	0.0482	0.516	.7533	0.5154	0.586	.6822	0.9940	0.650
.5795	0.0516	0.490	.7551	0.5201	0.582	.6878	0.0089	0.634
.5809	0.0553	0.456	.7566	0.5241	0.557	.6892	0.0126	0.633
.5823	0.0590	0.423	.7621	0.5389	0.497	.6906	0.0162	0.623
.5878	0.0738	0.352	.7635	0.5426	0.479	.6920	0.0200	0.605
.5893	0.0778	0.342	.7654	0.5476	0.458	.6975	0.0348	0.553
.5909	0.0822	0.306	.7671	0.5522	0.446	.6989	0.0385	0.535
.5922	0.0856	0.295	.7732	0.5686	0.382	.7003	0.0422	0.517
.5976	0.1001	0.244	.7747	0.5726	0.370	.7017	0.0459	0.509
.6032	0.1149	0.213	.7760	0.5760	0.350	.7072	0.0607	0.404
.6046	0.1186	0.205	.7774	0.5797	0.336	.7086	0.0644	0.380
						.7100	0.0681	0.400

TABLE IIIb.—Continued.

JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm
6484.7114	0.0719	+0.382	6508.6843	0.0367	+0.540	6511.6634	0.9857	+0.633
.7170	0.0867	0.296	.6856	0.0401	0.544	.6648	0.9894	0.639
.7183	0.0904	0.265	.6925	0.0587	0.441	.6662	0.9931	0.645
.7199	0.0944	0.274	.6939	0.0624	0.405	.6676	0.9968	0.645
.7211	0.0978	0.268	.6953	0.0661	0.389	.6731	0.0116	0.630
6508.5037	0.5550	+0.424	.6967	0.0698	0.367	.6745	0.0153	0.611
.5050	0.5584	0.405	.7036	0.0883	0.270	.6759	0.0190	0.608
.5065	0.5624	0.394	.7050	0.0920	0.259	.6773	0.0227	0.594
.5078	0.5658	0.370	.7064	0.0957	0.240	.6838	0.0400	0.526
.5133	0.5806	0.326	.7078	0.0994	0.240	.6852	0.0437	0.502
.5147	0.5843	0.302	.7133	0.1143	0.198	.6866	0.0474	0.485
.5162	0.5883	0.286	.7147	0.1180	0.176	.6879	0.0511	0.464
.5176	0.5920	0.287	.7161	0.1217	0.173	.6947	0.0691	0.386
.5232	0.6069	0.237	.7175	0.1254	0.164	.6960	0.0728	0.391
.5244	0.6102	0.233	6511.5069	0.5681	+0.380	.6974	0.0765	0.361
.5258	0.6140	0.233	.5077	0.5703	0.369	.6995	0.0820	0.327
.5273	0.6180	0.218	.5097	0.5756	0.344	.7053	0.0975	0.240
.5328	0.6325	0.169	.5111	0.5793	0.325	.7069	0.1018	0.237
.5343	0.6365	0.169	.5166	0.5941	0.271	.7083	0.1055	0.224
.5357	0.6402	0.163	.5182	0.5981	0.266	.7097	0.1092	0.190
.5371	0.6439	0.164	.5194	0.6015	0.244	.7153	0.1240	0.178
.5426	0.6587	0.144	.5208	0.6052	0.228	.7166	0.1277	0.172
.5439	0.6621	0.137	.5271	0.6219	0.198	.7180	0.1314	0.162
.5453	0.6658	0.135	.5285	0.6256	0.193	.7194	0.1351	0.151
.5468	0.6699	0.122	.5298	0.6293	0.184	6515.5630	0.3908	+0.196
.5523	0.6847	0.113	.5312	0.6330	0.176	.5643	0.3942	0.196
.5537	0.6884	0.108	.5376	0.6500	0.156	.5657	0.3979	0.200
.5550	0.6918	0.114	.5389	0.6534	0.162	.5671	0.4016	0.219
.5564	0.6955	0.099	.5403	0.6571	0.150	.5727	0.4164	0.277
.5621	0.7106	0.086	.5416	0.6608	0.140	.5740	0.4201	0.277
.5635	0.7143	0.072	.5472	0.6756	0.102	.5754	0.4238	0.294
.5647	0.7177	0.067	.5486	0.6793	0.104	.5769	0.4278	0.318
.5661	0.7214	0.067	.5500	0.6830	0.093	.5865	0.4535	0.430
.5718	0.7366	0.058	.5514	0.6867	0.100	.5879	0.4572	0.445
.5732	0.7403	0.058	.5570	0.7018	0.088	.5893	0.4609	0.464
.5744	0.7437	0.055	.5583	0.7053	0.079	.5908	0.4649	0.490
.5758	0.7474	0.061	.5597	0.7089	0.074	.5970	0.4812	0.549
.5946	0.7974	0.061	.5612	0.7130	0.071	.5983	0.4849	0.551
.5960	0.8011	0.066	.5743	0.7479	0.071	.5997	0.4887	0.573
.5974	0.8048	0.081	.5758	0.7519	0.064	.6011	0.4924	0.579
.5988	0.8085	0.086	.5771	0.7553	0.069	.6067	0.5072	0.572
.6099	0.8382	0.141	.5785	0.7590	0.067	.6082	0.5112	0.594
.6113	0.8419	0.152	.5840	0.7738	0.066	.6095	0.5146	0.570
.6127	0.8456	-0.156	.5854	0.7775	0.065	.6108	0.5183	0.573
.6140	0.8493	0.169	.5868	0.7812	0.071	.6171	0.5350	0.513
.6196	0.8641	0.163	.5882	0.7849	0.067	.6185	0.5387	0.503
.6210	0.8678	0.169	.5937	0.7997	0.087	.6200	0.5427	0.492
.6224	0.8715	0.175	.5951	0.8035	0.089	.6213	0.5461	0.472
.6239	0.8755	0.183	.5965	0.8072	0.094	.6268	0.5609	0.403
.6293	0.8900	0.230	.5979	0.8109	0.098	.6282	0.5646	0.384
.6307	0.8937	0.237	.6035	0.8257	0.106	.6297	0.5687	0.375
.6321	0.8975	0.252	.6048	0.8294	0.121	.6310	0.5720	0.356
.6335	0.9012	0.252	.6134	0.8523	0.151	.6367	0.5872	0.305
.6425	0.9253	0.358	.6148	0.8560	0.169	.6379	0.5906	0.287
.6439	0.9290	0.371	.6162	0.8596	0.174	.6393	0.5943	0.281
.6453	0.9327	0.378	.6229	0.8776	0.189	.6407	0.5980	0.269
.6467	0.9364	0.399	.6243	0.8813	0.195	.6463	0.6128	0.234
.6522	0.9512	0.472	.6257	0.8850	0.205	.6477	0.6165	0.227
.6536	0.9549	0.496	.6271	0.8887	0.209	.6492	0.6205	0.217
.6550	0.9586	0.507	.6326	0.9035	0.268	.6504	0.6239	0.207
.6564	0.9623	0.533	.6340	0.9072	0.281	.6560	0.6387	0.167
.6620	0.9771	0.614	.6354	0.9109	0.287	.6574	0.6425	0.160
.6633	0.9808	0.610	.6368	0.9146	0.302	.6589	0.6465	0.160
.6647	0.9845	0.620	.6423	0.9295	0.376	.6602	0.6500	0.160
.6661	0.9882	0.620	.6437	0.9332	0.421	.6657	0.6647	0.130
.6717	0.0031	0.635	.6451	0.9369	0.421	.6671	0.6684	0.128
.6731	0.0068	0.611	.6465	0.9406	0.421	.6686	0.6724	0.108
.6745	0.0105	0.617	.6535	0.9591	0.527	.6699	0.6758	0.106
.6758	0.0142	0.611	.6548	0.9628	0.535	.6914	0.7333	0.069
.6814	0.0290	0.564	.6562	0.9665	0.549	.6928	0.7370	0.069
.6828	0.0327	0.572	.6576	0.9702	0.577	.6942	0.7407	0.070

TABLE IIIb.—Continued.

JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm	JD Hel. 2430000 +	Phase	Δm
6515.6956	0.7444	+0.069	6519.5996	0.1612	+0.108	6519.6592	0.3202	+0.060
.7019	0.7613	0.058	.6009	0.1645	0.101	.6606	0.3239	0.065
.7032	0.7648	0.061	.6064	0.1794	0.078	.6675	0.3424	0.100
.7046	0.7684	0.057	.6078	0.1831	0.083	.6690	0.3464	0.109
.7063	0.7731	0.050	.6092	0.1868	0.073	.6703	0.3499	0.115
6519.5655	0.0701	0.360	.6107	0.1908	0.066	.6717	0.3535	0.124
.5670	0.0741	0.345	.6163	0.2056	0.062	.6773	0.3684	0.141
.5685	0.0781	0.332	.6177	0.2093	0.053	.6786	0.3721	0.143
.5700	0.0821	0.320	.6189	0.2127	0.053	.6800	0.3758	0.151
.5759	0.0978	0.260	.6203	0.2164	0.053	.6815	0.3798	0.164
.5774	0.1019	0.248	.6314	0.2461	0.027	.6870	0.3943	0.191
.5786	0.1053	0.232	.6328	0.2498	0.032	.6884	0.3980	0.209
.5801	0.1093	0.218	.6342	0.2535	0.034	.6899	0.4020	0.253
.5856	0.1238	0.185	.6356	0.2572	0.030	.6913	0.4057	0.245
.5870	0.1275	0.178	.6420	0.2742	0.035	.6968	0.4206	0.291
.5884	0.1312	0.168	.6432	0.2776	0.032	.6981	0.4240	0.297
.5898	0.1349	0.161	.6446	0.2813	0.030	.6995	0.4277	0.342
.5968	0.1537	0.126	.6460	0.2850	0.031	.7009	0.4314	0.343
.5981	0.1571	0.111	.6578	0.3165	0.049			

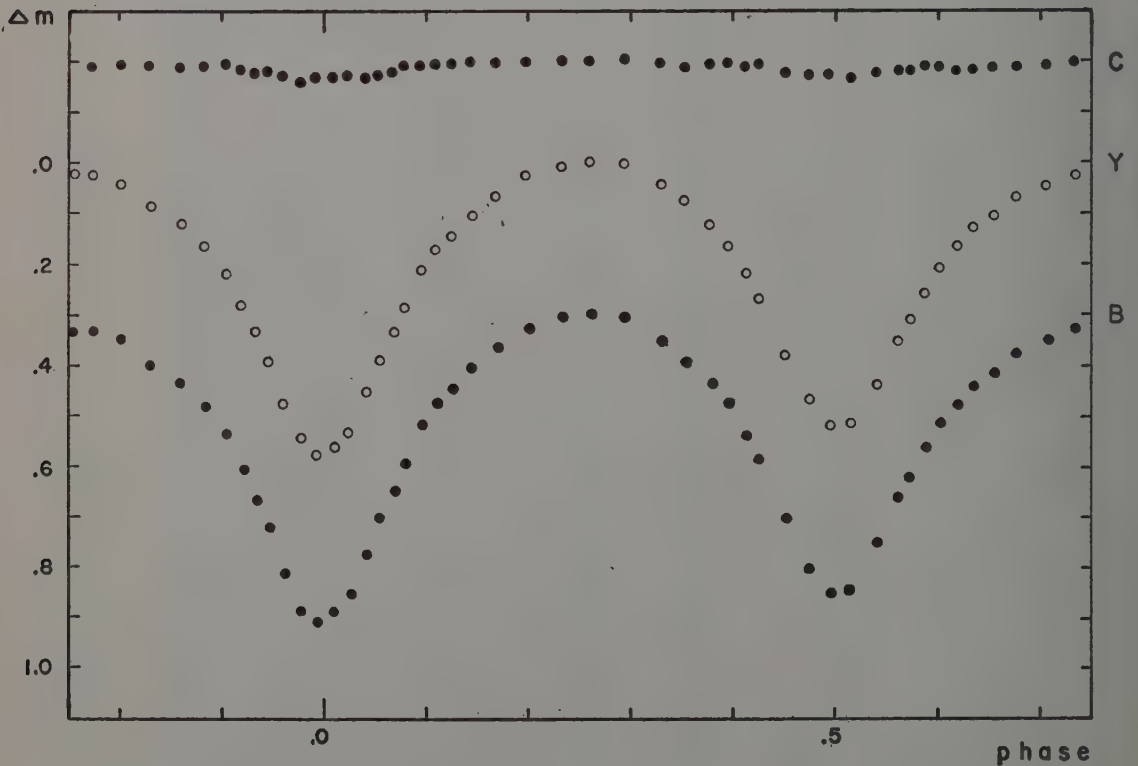


FIG. 2. The light curves and color curve of U Pegasi. The observations are B=blue, Y=yellow, C=color.

TABLE IV. Normal Points of U Pegasi.

Phase	Δm	n	Phase	Δm	n
Yellow			Blue		
0.0094	+0.565	12	0.0111	+0.594	12
0.0242	0.534	12	0.0257	0.555	11
0.0414	0.455	10	0.0432	0.478	10
0.0548	0.391	10	0.0564	0.406	10
0.0684	0.333	10	0.0701	0.349	10
0.0794	0.288	12	0.0805	0.294	12
0.0956	0.215	12	0.0971	0.220	12
0.1104	0.173	12	0.1121	0.175	12
0.1249	0.148	10	0.1266	0.148	10
0.1453	0.109	10	0.1469	0.105	10
0.1685	0.066	10	0.1713	0.064	9
0.1999	0.027	8	0.2016	0.028	8
0.2337	0.007	8	0.2354	0.001	8
0.2616	0.000	7	0.2634	0.000	7
0.2942	0.005	7	0.2961	0.004	7
0.3305	0.044	7	0.3330	0.051	6
0.3538	0.074	7	0.3556	0.091	7
0.3788	0.125	7	0.3808	0.135	7
0.3953	0.164	7	0.3969	0.175	7
0.4122	0.220	7	0.4139	0.238	7
0.4250	0.270	7	0.4268	0.285	7
0.4510	0.378	6	0.4528	0.405	6
0.4753	0.470	6	0.4771	0.502	6
0.4958	0.520	6	0.4975	0.550	6
0.5157	0.518	6	0.5174	0.545	6
0.5411	0.437	8	0.5430	0.450	8
0.5613	0.352	8	0.5630	0.361	8
0.5730	0.308	8	0.5743	0.321	8
0.5873	0.259	8	0.5889	0.261	8
0.6011	0.209	10	0.6028	0.213	10
0.6185	0.164	10	0.6202	0.178	10
0.6344	0.128	10	0.6360	0.138	10
0.6550	0.106	10	0.6569	0.115	10
0.6767	0.069	10	0.6784	0.076	10
0.7064	0.044	10	0.7080	0.050	10
0.7345	0.025	10	0.7356	0.027	10
0.7533	0.025	10	0.7550	0.033	10
0.7752	0.024	10	0.7769	0.032	10
0.8007	0.042	10	0.8025	0.049	10
0.8305	0.087	11	0.8321	0.099	10
0.8609	0.122	11	0.8626	0.135	10
0.8835	0.167	10	0.8851	0.180	10
0.9037	0.221	10	0.9053	0.236	10
0.9198	0.281	8	0.9217	0.306	8
0.9334	0.335	8	0.9351	0.367	8
0.9452	0.393	8	0.9470	0.423	8
0.9613	0.476	10	0.9630	0.515	10
0.9780	0.542	10	0.9797	0.588	10
0.9915	+0.575	12	0.9931	+0.608	12

TABLE V. Coefficients for the Light in the Maxima.

λ	A_0	A_1	A_2	B_1	B_2
LaFara's yellow and blue observations					
Y	+0.8858	-0.0193	-0.1128	-0.0033	-0.0036
	± 15	± 16	± 22	± 8	± 10
B	+0.8830	-0.0197	-0.1167	-0.0039	-0.0050
	± 16	± 17	± 23	± 8	± 10
Binnendijk's yellow and blue observations					
Y	+0.8800	-0.0100	-0.1112	+0.0121	-0.0064
	± 11	± 13	± 17	± 7	± 8
B	+0.8721	-0.0074	-0.1170	+0.0148	-0.0057
	± 12	± 14	± 19	± 7	± 9

TABLE VI. Orbital Elements Determination.

Obs.	Wendell	Schilt	LaFara	Binnendijk
Comp.	Shapley	Gaposchkin	Kopal	Binnendijk
x	0	0	0	1.0
k	1.00	0.64	1.00	0.82
α_0^{OC}	...	...	...	...
a_0	0.45	0.54	0.45	0.40
a_2	0.45	0.35	0.45	0.32
L_0	0.60	0.79	0.60	0.57
L_2	0.40	0.21	0.40	0.43
I_0/I_2	1.52	1.52	1.52	...
i	74°	71°	76°	78°
			68°	69°
				68°
				67°

angles. Least-squares solutions were made for the light in the maxima according to the formula,

$$I = A_0 + A_1 \cos \theta + A_2 \cos 2\theta + B_1 \sin \theta + B_2 \sin 2\theta.$$

The values for the constants are given in Table V together with their probable errors. The coefficient of $\cos 2\theta$ in LaFara's and in our observations remained the same within the probable errors. This means that the oblateness of the stars remained the same because the contribution of the reflection in this term is small. The coefficient of the $\sin 2\theta$ term is small and did not change appreciably. However, the coefficient of the $\sin \theta$ term changed its sign and this variation is considerable. There is also a change in the coefficient of the $\cos \theta$ term, which is possibly connected with this last change.

The intensities were first rectified for the $\sin \theta$ and $\sin 2\theta$ terms, which can be called perturbations. The normal rectifications for reflection and oblateness were carried out separately, and the phase angle was rectified.

The tables of J. E. Merrill (1950) were used in the determination of the orbital elements. The light losses in the rectified minima were respectively 0.158 and 0.150 for the yellow, and 0.181 and 0.166 for the blue intensities of the partial eclipses. A difficulty arose due to the fact that the durations of the rectified minima were not exactly the same; this is contrary to what would be expected for a circular orbit. The original light curves show that this is caused mainly by a slight deviation from the expected shape around phase 0.10. However, LaFara's observations coincide exactly with ours at this phase so this is no observational effect, but inherent in the system. The possibility of a slight eccentricity effect cannot be excluded, but the slight difference in the durations is likely caused by the presence of circumstellar material, for which the $\sin \theta$ and $\sin 2\theta$ terms give an insufficient representation.

Assuming a coefficient of limb darkening of $x=0.6$, the depth relation was found for the partial eclipses, which can be transformed into a relation between k and α_0^{OC} where the symbols have the usual meaning. Starting with these k , α_0^{OC} combinations, several theoretical light curves were computed and compared with the rectified intensities of the normal points. The compari-

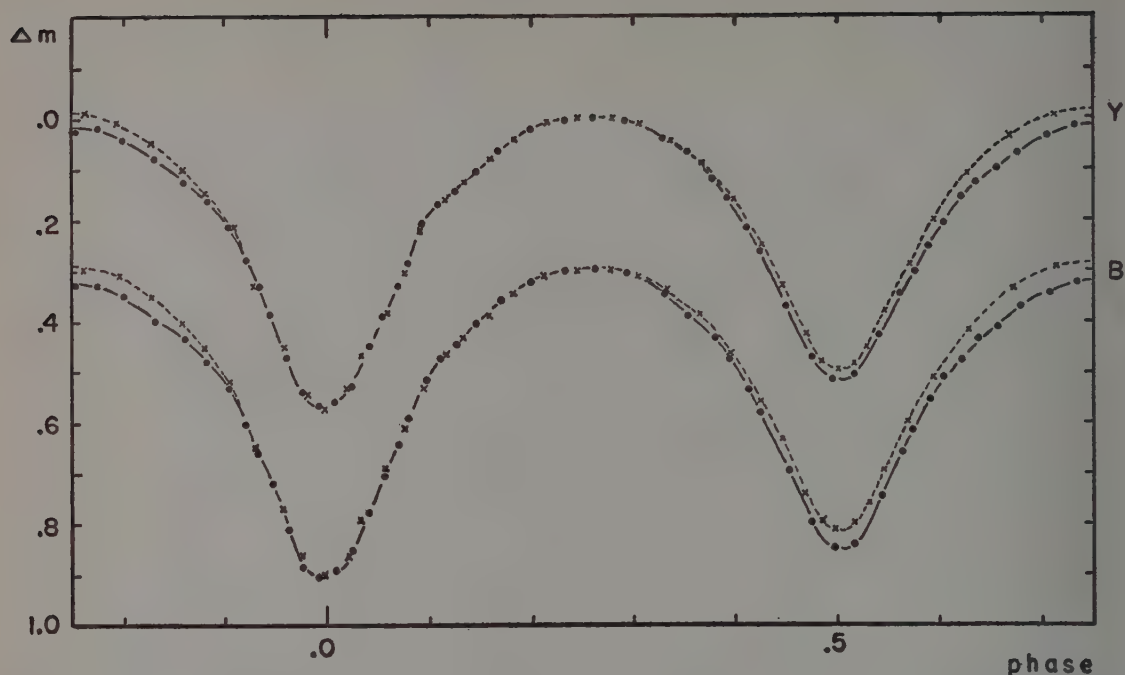


FIG. 3. Change in the light curves of U Pegasi as found from a comparison between LaFara's normals (1949-50) and ours, (1958). The crosses refer to LaFara's observations.

son with the shape of secondary minimum gave a good agreement for all possible combinations so that this part of the solution was indeterminate. The comparison with the shape of the other minimum was more successful. Primary minimum was found to be an occultation. From the few radial velocity measurements of O. Struve (1950) and collaborators, the same conclusion can be reached, as discussed by the author (Binnendijk 1957). In Table VI three solutions are given for three values of k to see the influence on the other orbital elements and to make a better comparison with other orbital solutions derived from older observations. The best value of the ratio of the radii is considered to be $k=0.7$.

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Observations of ϵ Aurigae

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Photoelectric observations made at the Flower and Cook Observatory, using the Pierce photometer and interference filters, are presented.

THE observations presented here were made with the Pierce photometer (Blitzstein 1953, 1958), mounted on the Flower and Cook Observatory 15-in. siderostat, and cover the observing seasons 1954 through 1958. The photometer was used as a single channel photometer for these observations. The observations during the first two seasons were made by F. B. Wood, the third season's observations were made by Wood and Fredrick, and the last two seasons' observations were by Fredrick. The filters used during the first four seasons are the same as those described by Wood and Blitzstein (1956). During the last season the old interference filters were replaced by new ones, the ultraviolet filter remaining the same. So far as can be determined, there is no systematic shift due to the change in the filters.

Observations from previous eclipses have been compiled by Güssow (1936). A photoelectric light curve of the 1928 to 1930 eclipse has been given by Huffer (1932). Light curves of the present eclipse have been published by Larsson-Leander (1958) and Huru-hata and Kitamura (1958), and in addition Gyldenkerne has circulated a plot of his observations made at Brørfelde.

The observations are tabulated in Table I. λ Aurigae was used as the comparison star and 2 Aurigae was used as the check star to check the constancy of λ Aurigae. The observations in the table are in the sense λ Aurigae minus ϵ Aurigae and are corrected for differential extinction; the epoch is heliocentric reckoned from Greenwich mean noon, and n refers to the number of observations making up a normal point. The observations have been plotted in Fig. 1 for each color. The scale for the variable is to the right of each plot. At the bottom of each plot the check star observations are plotted using slightly larger circles and the scale for these observations is on the left of each plot. The dashed line indicates a break in the time scale.

The light outside eclipse is remarkably constant as can be seen in the work by Güssow cited above. The variation about the mean light outside eclipse seldom exceeds 0.1 mag. From five to three years before or after eclipse the variation may get as large as, but seldom exceeds, 0.2 mag. During totality the variation is often as large as 0.3 mag, and perhaps a little larger. The intrinsic variation can be seen in the egress branch in

Fig. 1. A slight change in color accompanies the intrinsic variation. Our observations in the blue show excellent agreement with the light curve by Larsson-Leander, but show a discrepancy with the ultraviolet and blue observations of Huru-hata and Kitamura from JD 2435900 to 920. During the same interval, our observations in the yellow disagree with Larsson-Leander's yellow light curve but agree quite well with the observations of Huru-hata and Kitamura. This is as yet unexplained. The extremely high value of the ultraviolet observation on JD 2435542 is real, and is the mean of three very good observations.

It was originally hoped to combine the photometric information from a number of sources with the astrometric material collected at the Sproul Observatory during the past 20 years. A preliminary check of the Sproul material proved to be rather inconclusive as far as a possible astrometric orbit was concerned so the idea has been dropped until more material has been obtained.

The fact that the system loses the same amount of light in all colors has caused the system to receive a remarkable amount of attention during the past few decades. Perhaps more attention should be paid to another interesting aspect of the light curve of this system. During the total phase the light is not constant, as is often stated in the literature, but rather, totality deepens from second contact to third contact by about 0.1 mag. This is easily seen in the light curve given by Huffer and also in the one published by Larsson-Leander. The slope in each case is very nearly the same. If the eclipsing body is a cloud as is often suggested, it is quite difficult to visualize how this cloud can retain such a shape as to repeat the slope so consistently. The slope cannot be explained by a long term intrinsic variation as in the case of VV Cephei, because such a variation would be easily detected by visual observers and no such variation shows during the past 140 years.

ACKNOWLEDGMENT

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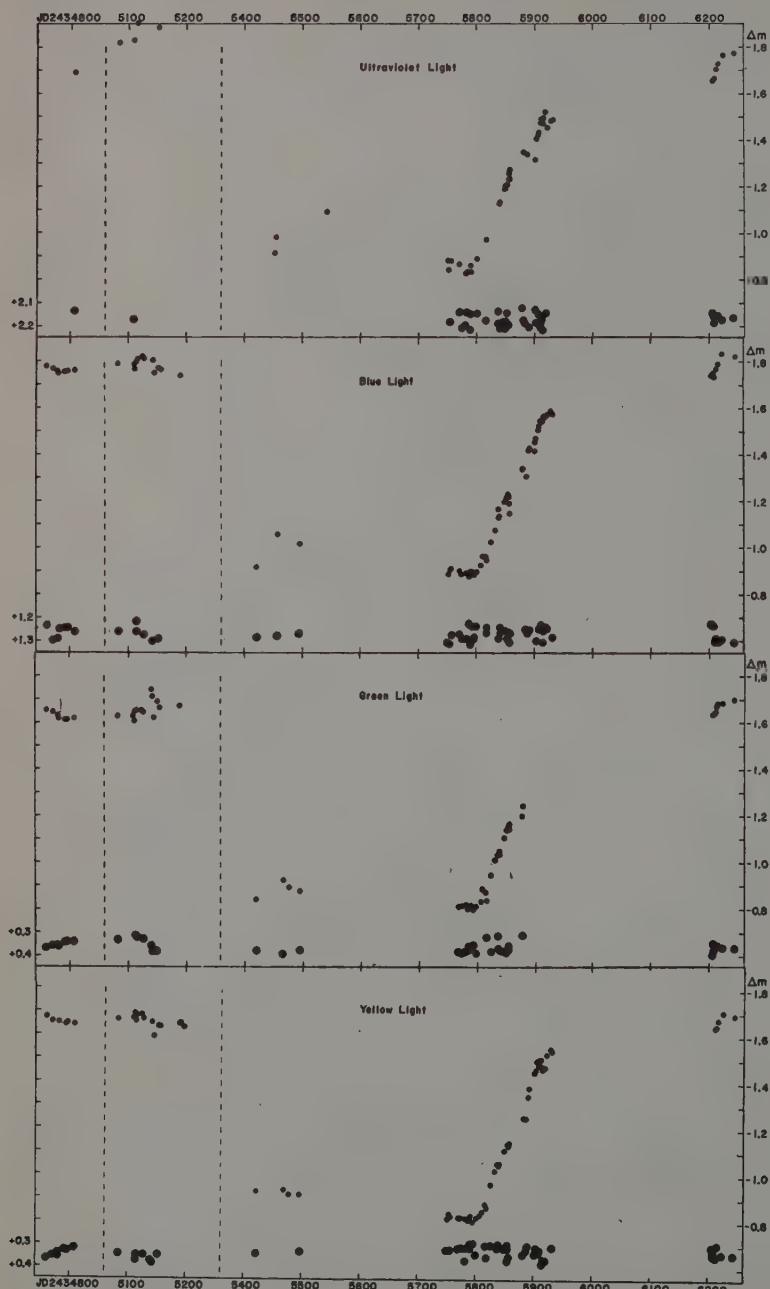


FIG. 1. Four-color observations of ϵ Aurigae. Small dots refer to the variable, large dots to the check star.

TABLE I.

Yellow light			Green light			Blue light			Ultraviolet light		
JD	Δm	n	JD	Δm	n	JD	Δm	n	JD	Δm	n
2434760.5219	-1.673	4	.5267	-1.650	4	.5235	-1.777	3			
771.5053	1.654	5	.5099	1.644	5	.5106	1.767	5			
780.5570	1.651	5	.5578	1.629	5	.5584	1.752	5			
781.5134	1.648	3	.5145	1.614	3	.5152	1.745	3			
792.5280	1.640	4	.5289	1.611	4	.5296	1.752	4			
796.4940	-1.649	4	.4950	-1.608	4	.4958	-1.755	3			
808.5128	1.642	3	.5136	1.613	3	.5143	1.756	3	.5485	-1.686	2
2435084.6103	1.660	4	.6138	1.625	4	.6147	1.783	4	.6578	1.819	1
110.6237	1.667	2	.6247	1.625	2	.6256	1.785	2	.5734	1.830	5
112.5422	1.689	1	.5432	1.603	1	.5439	1.762	1			
115.5467	-1.656	4	.5427	-1.642	3	.5436	-1.796	3			
116.5946	1.679	4	.5956	1.645	4	.5975	1.805	4	.5470	-1.903	4
125.5948	1.684	2	.5958	1.648	2	.5968	1.819	2			
128.5749	1.667	4	.5763	1.642	4	.5778	1.810	2			
142.5707	1.655	2	.5718	1.736	2	.5732	1.800	2			
143.6069	-1.647	5	.6156	-1.708	5	.6096	-1.802	4			
146.5267	1.592	2	.5281	1.620	2	.5300	1.795	2			
152.5363	1.636	4	.5374	1.688	4	.5384	1.769	4	.5811	-1.881	2
157.5206	1.632	2	.5216	1.662	2	.5229	1.758	2			
190.5296	1.646	2	.5305	1.668	2	.5316	1.735	2			
197.5176	-1.626	2									
2435422.6912	0.925	4	.6873	-0.839	4	.6884	-0.914	4	.6811	-0.912	2
453									.5928	0.983	3
455											
458						.6568	1.037	2			
469.5882	-0.932	2	.5894	-0.921	2						
479.6069	0.911	1	.6078	0.892	1						
497.5765	0.911	7	.5775	0.872	7	.5784	-1.015	7			
542									.5568	-1.090	3
2435752.8072	0.811	4				.8083	0.880	4	.8058	0.842	4
755.8076	-0.836	5				.8087	-0.905	5	.8185	-0.878	5
757.8020	0.824	10				.8148	0.908	10	.8122	0.882	10
771.8214	0.820	12	.8189	-0.810	12	.8166	0.898	12	.8176	0.866	5
775.8060	0.818	9	.8070	0.810	9	.7998	0.881	9	.7995	0.887	5
782.8081	0.822	16	.8037	0.817	16	.8047	0.894	16	.7798	0.830	6
783.7653	-0.818	13	.7709	-0.817	13	.7719	-0.895	13	.7866	-0.832	5
788.7976	0.809	3	.7985	0.800	3	.7994	0.874	3			
790.7589	0.804	9	.8217	0.801	3	.7656	0.890	9	.7792	0.859	4
791.7515	0.812	5	.7525	0.801	5	.7408	0.901	5	.8258	0.835	7
792.7242	0.826	4	.7251	0.813	4	.7260	0.899	4			
793.7238	-0.816	4	.7247	-0.800	4	.7326	-0.884	4			
796.7332	0.802	6	.7442	0.794	6	.7453	0.882	6			
801.7106	0.816	6	.7112	0.810	6	.7118	0.895	6	.7525	-0.889	4
808.6827	0.828	3	.6838	0.831	3	.6847	0.924	3			
811.6482	0.843	4	.6491	0.883	4	.6561	0.964	4			
817.6795	-0.877	7	.6763	-0.870	7	.6813	-0.962	7	.7545	-0.974	4
819.7058	0.858	6	.7029	0.835	6	.6852	0.945	6			
826.6632	0.963	3	.6643	0.944	3	.6652	1.024	3			
833.6202	1.020	1	.6211	1.007	1	.6229	1.074	1			
838.5690	1.049	7	.5757	1.032	7	.5790	1.166	7			
840.6342	-1.046	6	.6351	-1.031	6	.6360	-1.126	6	.6558	-1.121	3
841.5852	1.048	7	.5861	1.042	7	.5762	1.132	7	.6269	1.132	5
849.5941	1.107	9	.5951	1.104	9	.6020	1.194	9	.6342	1.203	6
853.5690	1.124	5	.5699	1.138	5	.5708	1.211	5	.6285	1.206	6
855.6097	1.134	4	.6050	1.149	4	.6059	1.228	4	.6535	1.233	2
856.5599	-1.126	5	.5608	-1.150	5	.5675	-1.220	5	.6210	-1.259	6
857.5921	1.137	2	.5930	1.148	3	.5939	1.190	3	.6458	1.234	2
858.5592	1.136	6	.5538	1.142	6	.5547	1.147	6	.6230	1.271	6
880			.5042	1.198	1						
881.5271	1.252	5	.5111	1.239	5	.5051	1.342	5	.5781	1.351	5
887.5198	-1.243	5				.5192	-1.305	5	.5481	-1.338	2
890.5302	1.340	5				.5357	1.418	5	.5846	1.415	3
891.5221	1.374	3				.5222	1.426	3			
901.5633	1.438	4				.5639	1.413	4			
902.5501	1.495	1				.5510	1.451	1	.5300	1.316	3

TABLE I.—Continued.

Yellow light			Green light			Blue light			Ultraviolet light		
JD	Δm	n	JD	Δm	n	JD	Δm	n	JD	Δm	n
903.5179	-1.451	4				.5237	-1.470	4	.5548	-1.406	2
907.5875	1.500	4				.5884	1.506	4	.5606	1.424	3
908.5607	1.476	4				.5616	1.521	4	.5267	1.432	3
910.5616	1.476	4				.5620	1.543	4	.5182	1.474	3
911									.5346	1.490	2
912.5618	-1.500	3				.5627	-1.540	3	.5304	-1.473	4
914.5592	1.453	3				.5582	1.543	3	.5262	1.470	3
915.5552	1.471	3				.5548	1.565	3	.5255	1.493	3
919.5425	1.463	3				.5434	1.566	3	.5193	1.521	2
921.5533	1.522	4				.5543	1.572	4	.5289	1.454	3
929.5435	-1.542	3				.5444	-1.588	3	.5284	-1.482	2
931.5572	1.528	2				.5583	1.572	2	.5391	1.486	3
2436207.5659	1.642	3	.5668	-1.636	3	.5677	1.744	3	.6154	1.655	3
208.5660	1.642	2	.5669	1.640	2	.5678	1.748	2	.6090	1.658	2
209.5813	1.642	2	.5822	1.633	2	.5831	1.736	2	.6341	1.664	2
212.5768	-1.647	2	.5777	-1.669	2	.5786	-1.770	2	.6146	-1.704	2
215.5762	1.672	2	.5771	1.682	2	.5780	1.792	2	.6119	1.728	2
223.5826	1.706	1	.5835	1.683	1	.5844	1.832	1	.6093	1.763	1
243.5788	1.692	2	.5797	1.697	2	.5806	1.822	2	.5620	1.770	2

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Twenty Variable Stars in Sagittarius

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Periods have been determined for 20 variable stars in VSF 193 in Sagittarius: one semi-regular, one Algol, 17 typical Mira-type, and one (K0 Sgr) with a period of 312 days whose light curve suggests a U Geminorum star, but which is probably a long-period variable with a faint companion.

IN continuation of the program of work on Variable Star Field 193 in Sagittarius (Hoffleit 1957, 1958, 1959), periods have been determined for 20 more variable stars (Table I). Four of them had not previously been announced as variable and are given the temporary designations a through d in Table I. Variable a is semi-regular and variable d an Algol-type binary. The others are long-period variables, all but K0 Sgr appearing to have typical Mira-type light curves with periods from 175 to 300 days. Identification charts for variables a, d and K0 Sgr are given in Fig. 1, the variable in each case is the brightest star within the small circle.

The entries in Table I include the Julian date minus 2400000 of a well-defined maximum in the case of the

long-period variables and of a minimum for the eclipsing variable, the number of epochs included in the determination of the period, and the type of variation. The two columns headed obs. and c give initials representing the women who made the estimates of magnitude, and those who derived the periods. They are: A, Jean Hales Andersen; B, Jennifer Bagster-Collins; C, Marguerite Camusso; F, Margo Friedel; H, D. Hoffleit; L, Ida Lowell; M, Janet Marshall; P, Zora Prochazka; and W, Barbara Welther.

The observations of the semi-regular variable, a, obtained on Harvard plates of the A, B and MF series, taken with the 24-in. Bruce, 8-in. Bache, and 10-in. Metcalf photographic refractors, respectively, are shown in Fig. 2. No single period has been found to fit

TABLE I. New periods for variable stars in VSF 193.

Var. Sgr	R.A. (1900) Dec.	Max pg	Min pg	Period	JD	Ep.	Type	Obs.	C	Rejected Period
a	18 ^h 09 ^m 42 ^s -24°54'8	13.5	15.8	80-140 ^d	—	—	SR	P, W	W, H	
G0	16 03 -25 57.8	13.0	[16.2]	243	26200	52	Mira	W, H	W, H	245
GX	19 17 -24 44.8	13.8	[16.3]	262	32060	40	"	M, W	W, H	
b	20 04 -26 08.6	13.5	16.5	175	31600	73	"	A, W	W, H	
HK	20 06 -24 42.2	13.4	16.4	293	32380	33	"	A, M, W	H	
LO	20 20 -27 00.3	13.3	16.0:	178	26120	46	"	L	L	
HP	20 51 -26 27.0	13.4	[15.8]	231	26130	43	"	L	L	
c	21 16 -26 17.4	15.0	[16.5]	279	26900	45	"	H	H	
HU	22 54 -25 08.3	13.5	[16.0]	260	33838	51	"	C	C	258
HX	24 08 -26 50.7	13.7	15.9	209	25750	47	"	L	L	
IL	25 39 -25 43.7	13.8	[16.3]	215	24380	46	"	C	C	
IM	25 53 -25 17.6	11.8	15.9:	275	26160	46	"	C	C	283
HV 9461	26 25 -26 39.8	13.5	[15.6]	223	25800	44	"	L	L	
LW	29 26 -27 45.3	13.8	[16.0]	299	26100	33	"	L	L	
IV	29 29 -24 13.9	14.0	[16.0]	226:	23950	57	"	B	H	
V 945	30 53 -27 47.2	13.8	17.0:	250	25800	40	"	L	L	230
d	31 09 -20 08.8	14.6	15.4	5.8674	25417.502	1690	Algol	F, H	H	
HV 9486	31 56 -27 03.7	13.5	15.6	241	25400	41	Mira	L	L	
KM	32 43 -23 58.1	13.7	16.0:	255	27270	50	"	B, M	H	
KO	34 32 -20 45.7	12.7	15.8	312	24380	42	Mira?	F, H	H	

all the observations. The apparent lengths of well-defined cycles of light variation range from perhaps 100 to 140 days. The observations plotted are the means of observations made by Zora Prochazka at Harvard several years ago and re-estimates made last summer by Barbara Welther at the Maria Mitchell Observatory. Magnitude estimates by Miss Welther on additional plates taken in the last three years with the 7.5-in. Cooke photographic triplet at the Maria Mitchell Observatory show the star at maximum, brighter than 14.0 mag, on JD 36050-075, 36400 and 36720; and at minimum, fainter than 14.7 mag, on JD 36035, 36105-130, 36345, and 36750. These recent observations are adequately represented by a period of only 80 days.

The Algol-type star, variable d, was observed in eclipse on ten nights: JD 24355.669, 24402.554, 25417.502, 25423.493, 25775.553, 25881.242, 26162.566, 26872.571, 28345.534, and 29906.261. These, as well as the observations at maximum, are satisfied by the reciprocal period, 0.170435.

Relatively few variables in this rich star-field have been found with periods exceeding 300 days. The one such probable Mira-type star in the present list, KO Sgr, appears atypical. Normally at minimum below 15 mag, the star suddenly brightens by more than two magnitudes and remains at maximum only about 50 days. Table II gives the magnitude estimates for the best-

observed maximum together with the estimates for the nearest observed preceding and following minimum. The shape of the observed light curve is more reminiscent of cataclysmic than Mira-type variables, especially as only one other observation at maximum was found on the plates of the MF series which ordinarily

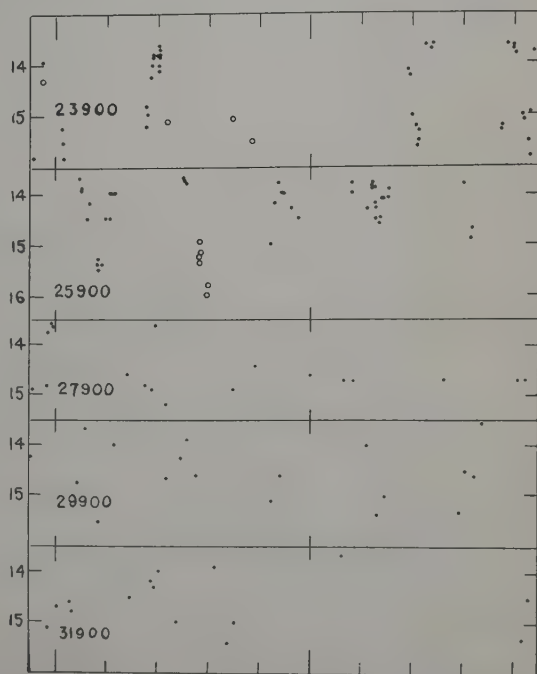


FIG. 2. Observations on Harvard plates of the semi-regular variable, a. Abscissa-markers indicate intervals of 200 days; ordinates indicate photographic magnitudes. Numbers within the figure indicate the Julian date of the beginning of each strip.

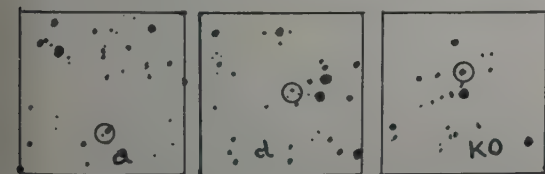


FIG. 1. Environment of variables a, d, and KO Sgr. Width of charts about 10' arc.

TABLE II. An outburst of K0 Sgr.

JD	Mag pg	JD	Mag pg
24023	15.7	24377	12.7
24352	14.7	99	13.1
53	14.7	401	13.3
55	14.7	02	13.6
57	14.6	03	13.6
71	13.2	04	13.4
73	13.0	05	13.4
74	13.0	06	13.8
76	12.9	25383	15.5

yield half of our observational data. Nevertheless, the intervals between the observed flares on these and other plates satisfy a regular period of 312 days. Isolated observations at maximum occurred on JD 26872, 28430, 28740, 31270, and 33130. A composite light curve representing all positive observations is given in Fig. 3. It is probable that the observations at minimum represent either an optical or physical companion of about 15.8 mag. Spectroscopic observations would be of considerable interest.

For four of the Mira-type variables in Table I (G0 Sgr, Luyten 1927b; HU and IM Sgr, Luyten 1927a; and V945 Sgr, Innes 1917), the periods given in the final column, based upon relatively few observations, had previously been published elsewhere. Our independently determined values sufficiently represent such older observations or epochs of maximum as have been published, whereas the previously determined periods do not represent all of the present data, which amount to over 300 observations per star.

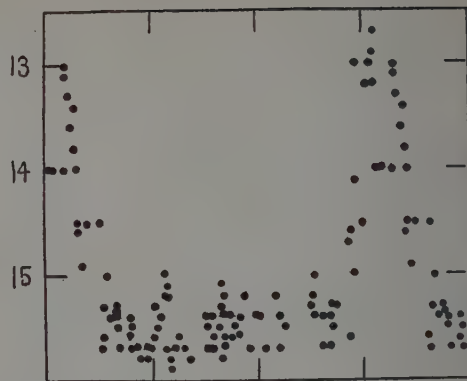


FIG. 3. Observations of K0 Sgr fitted to a period of 312 days. Markers indicate intervals of 100 days and 1 mag.

ACKNOWLEDGMENT

More than half the magnitude estimates and all the computations for periods represented in this paper have been accomplished since June, 1959, under a contract with the Office of Naval Research, for which we express our sincere appreciation.

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Discussion of Occultations Observed in 1956 and 1957*

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A summary of the results of the analysis of the occultation observations for 1956 and 1957 is presented here.

THIS discussion is a continuation of the series of which the one for 1953 to 1955 appeared in *Astron. J.* **63**, 244 (1958). The occultations included are all disappearances at the dark limb and have been restricted to stars whose positions are derived from the *Zodiacal Catalogue* (Robertson 1940). Results are also given for solutions which have been made including reappearances at the dark limb and bright limb observations of bright stars.

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Reductions of all the observations received were performed using punched-card machines, with a provisional correction of $-4''.0$ applied to the moon's tabular mean longitude. Observations which gave impossible results were discarded at this stage. In the present discussion are included observations from 171 observers at 85 stations for 1956 and from 203 observers at 95 stations for 1957. These observations will be published in a combined list showing details of observation and reduction, together with residuals from the adopted solution for each lunation.

TABLE I. Normal equations and solutions.

Lun.	<i>n</i>	$[\dot{p}\dot{p}]$	$[\dot{p}q]$	$[q\dot{q}]$	$[\dot{p}\Delta\sigma]$	$[q\Delta\sigma]$	δL_1	pe	δB_1	pe	δL_q	δB_q
1956												
"												
408											+0.26	-0.48
409	79	48.29	+11.01	30.71	+ 23.1	- 11.5	+0.61	± 0.07	-0.59	± 0.09	+0.65	-0.54
410	110	73.13	+ 2.48	36.87	+ 58.4	- 15.4	+0.84	0.06	-0.47	0.08	+0.78	-0.40
411	117	81.21	-14.63	35.79	+ 68.2	- 15.0	+0.91	0.06	-0.08	0.09	+0.80	-0.34
412	105	72.81	+15.49	32.19	+ 41.0	- 3.0	+0.70	0.06	-0.41	0.09	+0.77	-0.33
413	59	44.32	+ 3.02	14.68	+ 29.1	- 6.3	+0.76	0.08	-0.57	0.13	+0.71	-0.50
414	36	27.05	- 5.61	8.95	+ 16.8	- 10.0	+0.52	0.10	-0.84	0.18	+0.51	-0.77
415	34	24.73	- 1.52	9.27	+ 0.3	- 11.0	0.00	0.10	-1.20	0.16	+0.13	-1.29
416	101	64.07	+ 9.95	36.93	- 13.9	- 49.8	+0.06	0.06	-1.35	0.08	+0.01	-1.37
417	67	36.38	+ 4.30	30.62	- 11.1	- 44.9	-0.07	0.08	-1.45	0.09	-0.02	-1.27
418	79	49.46	+ 0.31	29.54	- 4.9	- 29.5	-0.06	0.07	-1.00	0.09	-0.11	-1.21
419	47	32.83	+ 2.43	14.17	- 10.5	- 16.6	-0.24	0.09	-1.13	0.13	-0.02	-1.04
420	48	34.40	+ 1.54	13.60	+ 7.6	- 13.7	+0.27	0.09	-1.04	0.14	+0.05	-0.80
409-420	882	588.68	+28.77	293.32	+204.1	-226.7	+0.44		-0.81			
1957												
"												
421	59	39.40	+ 9.81	19.60	- 3.3	- 7.2	+0.01	± 0.09	-0.37	± 0.13	+0.10	-0.35
422	61	44.72	+ 3.15	16.28	+ 2.6	+ 5.2	+0.04	0.08	+0.31	0.13	-0.17	+0.14
423	100	75.16	+18.68	24.84	- 22.3	+ 5.2	-0.43	0.07	+0.53	0.12	-0.03	+0.27
424	241	133.01	+ 1.92	107.99	+ 19.3	+ 28.6	+0.14	0.05	+0.26	0.05	+0.06	+0.10
425	46	24.59	- 1.21	21.41	+ 18.1	- 16.8	+0.70	0.11	-0.75	0.11	+0.26	-0.08
426	54	33.87	- 3.27	20.13	+ 13.2	- 24.3	+0.28	0.09	-1.16	0.12	+0.39	-0.94
427	44	27.26	- 1.35	16.74	+ 7.7	- 16.2	+0.24	0.10	-0.95	0.13	-0.30	-1.44
428	70	51.69	+ 7.79	18.31	- 58.8	- 39.9	-0.86	0.08	-1.81	0.13	-0.54	-1.57
429	59	44.38	+ 1.45	14.62	- 28.5	- 26.2	-0.59	0.08	-1.73	0.14	-0.84	-1.73
430	81	53.76	+25.69	27.24	- 99.0	- 67.3	-1.20	0.10	-1.34	0.14	-0.83	-1.71
431	37	23.00	+ 1.54	14.00	- 21.9	- 25.8	-0.84	0.11	-1.75	0.14	-1.06	-1.37
432	58	38.56	- 0.14	19.44	- 38.9	- 19.1	-1.01	0.08	-0.99	0.12	-0.75	-1.14
421-432	910	589.40	+64.06	320.60	-211.8	-203.8	-0.30		-0.58			

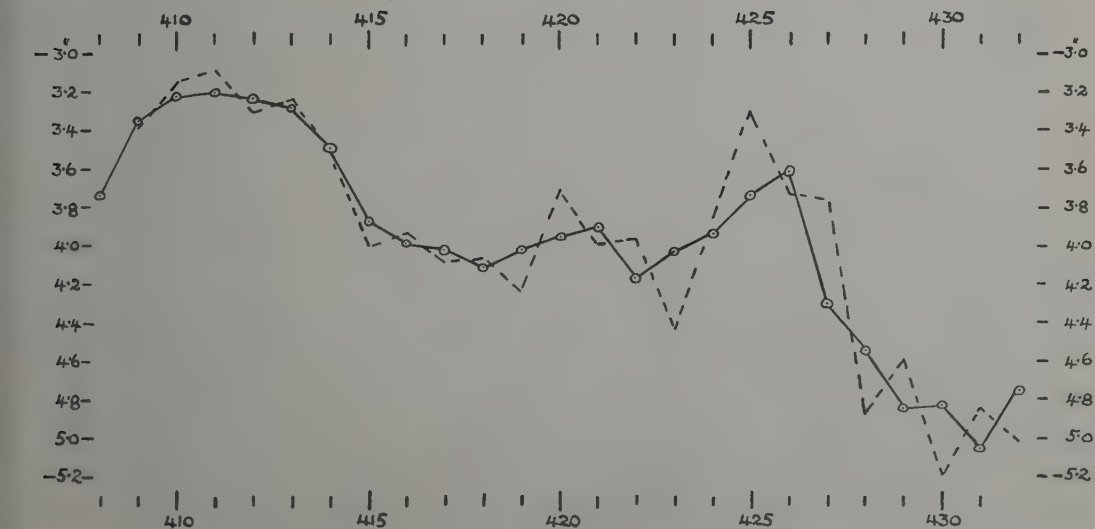


FIG. 1. Occultations 1956 and 1957. Observed deviations of the moon from its tabular mean longitude. Open circles represent running quarterly solutions; the dotted line, results for individual lunations.

The discussion covers 24 lunations, 409 to 420 for 1956, and 421 to 432 for 1957. The total numbers of observations originally considered for these two years were 916 and 945, of which 34 and 35, respectively, were rejected. Several of these rejected observations are certain to be included in the rediscussion, when corrections for irregularities of the moon's limb have been applied. The average number of observations in a lunation is 75, but the distribution is uneven. In 1956 the numbers of observations in a lunation vary from 34 to 117, and in 1957 from 37 to 100, except for lunation 424 which has 241 observations.

The solutions were made by the method of least squares from the observational equation

$$p\delta L + q\delta B = \Delta\sigma.$$

The normal equations and their solutions are given in Table I, the values of δL_q and δB_q representing quarterly solutions. The values of δL for lunations 410 to 418 have been corrected by small quantities between 0".03 and 0".07 to compensate for the intermittent failure of the punched-card calculating machine to read the final digit in the second difference of the moon's right ascension during the reductions. The observations concerned will be reduced again before the rediscussion. The mean errors of a single observation for 1956 and 1957 are 0".74 and 0".78 corresponding to probable errors of 0".50 and 0".53 if the distribution were normal,

and these values have been used to compute the probable errors in the table. The distribution is not normal and varies in different lunations; the residuals for half the observations in 1956 and 1957 are less than 0".47 and 0".52, respectively.

The arithmetic means of the twelve lunations in 1956 and in 1957 give the following results:

Mean epoch	δL	δB
1956.50	$-3".63 \pm 0".023$	$-0".84 \pm 0".034$
1957.50	-4.29 ± 0.025	-0.81 ± 0.036

The solutions, including reappearances at the dark limb and bright limb observations of bright stars, yield the following results based on 1025 observations for 1956 and 1024 observations for 1957.

Mean epoch	δL	δB
1956.50	$-3".64 \pm 0".021$	$-0".80 \pm 0".032$
1957.50	-4.37 ± 0.024	-0.74 ± 0.034

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Ephemeris for Physical Observations of Jupiter near Conjunction

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The ephemeris for physical observations of Jupiter during the intervals near conjunction that are omitted from the *American Ephemeris* is given for 1960, 1961, and 1962, for the reduction of radio observations.

THE widespread interest in radio observations of Jupiter, and the feasibility of making these observations much nearer conjunction than is possible for optical observations, have led to requests for extensions of the ephemeris for physical observations now given in the *American Ephemeris* and in the *Astronomical Ephemeris*, where an interval near conjunction is omitted. Beginning with 1963, the ephemeris will be extended through this interval; meanwhile, the extensions for 1960, 1961, and 1962, are given here in Tables I and II, in the same form as the ephemeris in the 1960 volumes.

An additional System III for the central meridian

has been defined by the radio observers at the University of Florida (Carr 1959). It coincided with System II at 0^h UT on January 1, 1957, and has a rotation period of 9^h55^m28^s.8, which is 11^s.8 less than System II. The central meridian of System II may be reduced to System III by applying the correction

$$+0".2882(\text{JD} - 243\,5839.5) - 0".00166\Delta,$$

where Δ is the geocentric distance of Jupiter.

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TABLE I. Ephemeris for physical observations for 0^h universal time.

Date	Light-time <i>m</i>	Stellar Magnitude	Diameter		<i>A_E+180°</i>	<i>D_E</i>	<i>A_S+180°</i>	<i>D_S</i>	<i>i</i>	Defect of Illumi- nation	Position angle of		Central meridian		Correction for phase
			Equatorial	Polar							Defect	Axis	System I	System II	
			"	"							°	°	°	°	
1960															
Dec. 8	50.59	-1.4	32.35	30.19	142.32	-1.79	146.53	-1.69	4.20	0.04	86.42	355.16	179.52	304.69	-0.08
12	50.77	1.4	32.24	30.09	143.22	1.77	146.87	1.68	3.63	0.03	86.07	354.75	90.12	184.77	0.06
16	50.92	1.4	32.14	30.00	144.13	1.74	147.20	1.66	3.06	0.02	85.75	354.34	0.72	64.86	0.04
20	51.04	1.4	32.07	29.93	145.04	1.72	147.53	1.65	2.48	0.02	85.44	353.92	271.34	304.95	0.03
24	51.13	1.4	32.01	29.87	145.96	1.69	147.87	1.63	1.90	0.01	85.19	353.51	181.96	185.05	0.02
28	51.20	-1.4	31.97	29.83	146.88	-1.67	148.20	-1.62	1.30	0.00	85.06	353.09	92.59	65.17	-0.01
1961															
Jan. 1	51.23	1.4	31.94	29.81	147.81	1.64	148.53	1.60	0.71	0.00	85.35	352.67	3.24	305.30	0.00
5	51.24	1.4	31.94	29.81	148.74	1.61	148.87	1.59	0.12	0.00	92.72	352.26	273.91	185.44	0.00
9	51.22	1.4	31.95	29.82	149.67	1.58	149.20	1.57	0.48	0.00	260.87	351.85	184.59	65.60	0.00
13	51.17	1.4	31.98	29.85	150.60	1.56	149.54	1.56	1.08	0.00	261.71	351.44	95.29	305.78	+0.01
17	51.09	-1.4	32.03	29.89	151.53	-1.53	149.87	-1.54	1.67	0.01	261.69	351.03	6.01	185.98	+0.01
21	50.99	1.4	32.10	29.96	152.46	1.50	150.21	1.53	2.26	0.01	2641.8	350.63	276.75	66.20	0.02
25	50.85	1.4	32.18	30.04	153.38	1.47	150.54	1.51	2.85	0.02	261.21	350.24	187.51	306.44	0.04
29	50.69	1.4	32.28	30.13	154.29	1.44	150.88	1.49	3.42	0.03	260.92	349.85	98.29	186.71	0.05
Feb. 2	50.50	-1.4	32.40	30.24	155.20	-1.41	151.21	-1.48	3.99	0.04	260.61	349.46	9.10	67.00	+0.07
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1961															
Dec. 31	48.81	-1.6	33.53	31.29	173.92	-0.32	179.70	-0.02	5.78	0.09	75.39	342.37	214.21	258.93	-0.15
1962															
Jan. 4	49.07	1.6	33.35	31.13	174.81	0.29	180.05	0.00	5.24	0.07	75.27	342.08	124.76	138.97	0.12
8	49.29	1.5	33.20	30.99	175.72	0.26	180.40	+0.02	4.68	0.06	75.19	341.80	35.32	19.01	0.10
12	49.49	1.5	33.07	30.86	176.63	0.22	180.75	0.04	4.12	0.04	75.16	341.51	305.88	259.05	0.07
16	49.67	1.5	32.95	30.75	177.56	0.19	181.11	0.06	3.54	0.03	75.21	341.23	216.45	139.10	0.06
20	49.81	-1.5	32.85	30.66	178.49	-0.15	181.46	+0.08	2.96	0.02	75.40	340.95	127.03	19.16	-0.04
24	49.93	1.5	32.77	30.59	179.44	0.12	181.81	0.10	2.37	0.01	75.80	340.67	37.61	259.26	0.02
28	50.02	1.5	32.71	30.53	180.38	0.08	182.16	0.12	1.78	0.01	76.66	340.40	308.21	139.30	0.01
Feb. 1	50.09	1.5	32.67	30.49	181.34	-0.04	182.51	0.13	1.18	0.00	78.65	340.13	218.82	19.39	-0.01
5	50.12	1.5	32.65	30.47	182.29	0.00	182.86	0.15	0.58	0.00	85.25	339.87	129.44	259.49	0.00
9	50.13	-1.5	32.64	30.47	183.25	+0.04	183.22	+0.17	0.14	0.00	176.90	339.61	40.08	139.61	0.00
13	50.11	1.5	32.66	30.48	184.20	0.08	183.57	0.19	0.66	0.00	239.40	339.36	310.73	19.74	0.00
17	50.07	1.5	32.69	30.51	185.16	0.12	183.92	0.21	1.25	0.00	244.90	339.12	221.41	259.90	+0.01
21	49.99	1.5	32.74	30.55	186.11	0.16	184.27	0.23	1.85	0.01	246.70	338.88	132.10	140.07	0.01
25	49.89	-1.5	32.80	30.62	187.06	+0.20	184.63	+0.25	2.44	0.01	247.52	338.65	42.82	20.27	+0.03

TABLE II. Longitude of central meridian of illuminated disk for 0^h universal time.

Day	System I				System II			
	1960		1962		1960		1962	
	Dec.	Jan.	Feb.	Jan.	Dec.	Jan.	Feb.	Jan.
1	...	3°2	211°5	11°7	...	305°3	277°0	48°8
2	...	160.9	9.2	169.4	...	95.3	67.1	198.8
3	...	318.6		327.0	...	245.4		348.8
4	...	116.2		124.6	...	35.4		138.8
5	...	273.9		282.3	...	185.4		288.9
6	224.1	71.6		79.9	4.6	335.5		78.9
7	21.8	229.2		237.6	154.6	125.5		228.9
8	179.4	26.9		35.2	304.6	275.6		18.9
9	337.1	184.6		192.9	94.6	65.6		168.9
10	134.8	342.3		350.5	244.7	215.6		318.9
11	292.4	139.9		148.2	34.7	5.7		109.0
12	90.1	297.6		305.8	184.7	155.7		259.0
13	247.7	95.3		103.5	334.7	305.8		49.0
14	45.4	253.0		261.1	124.8	95.8		199.0
15	203.0	50.7		58.7	274.8	245.9		349.0

TABLE II.—Continued.

Day	System I					System II				
	1960	1961		1962		1960	1961		1962	
	Dec.	Jan.	Feb.	Jan.	Feb.	Dec.	Jan.	Feb.	Jan.	Feb.
16	0.7	208.3		216.4	63.7	64.8	35.9		139.0	109.9
17	158.3	6.0		14.0	221.4	214.8	186.0		289.1	259.9
18	316.0	163.7		171.7	19.1	4.9	336.0		79.1	49.9
19	113.7	321.4		329.3	176.8	154.9	126.1		229.1	200.0
20	271.3	119.1		127.0	334.4	304.9	276.2		19.1	350.0
21	69.0	276.8		284.6	132.1	95.0	66.2		169.1	140.1
22	226.6	74.5		82.3	289.8	245.0	216.3		319.2	290.1
23	24.3	232.2		239.9	87.5	35.0	6.3		109.2	80.2
24	181.9	29.8		37.6	245.2	185.0	156.4		259.2	230.2
25	339.6	187.5		195.2	42.8	335.1	306.5		49.2	20.3
26	137.3	345.2		352.9		125.1	96.5		199.2	
27	294.9	142.9		150.5		275.1	246.6		349.3	
28	92.6	300.6		308.2		65.2	36.7		139.3	
29	250.2	98.3		105.8		215.2	186.8		289.3	
30	47.9	256.1		263.5		5.2	336.8		79.3	
31	205.6	53.8		61.2		155.3	126.9		229.4	

Photographic Determinations of the Parallaxes of Fifty-Five Stars with the Thaw Refractor

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(Received December 7, 1959)

In continuation of previous lists from Allegheny Observatory, the parallaxes of 55 stars are presented.

THE present list (Table I) of parallaxes from the Allegheny Observatory is a continuation of that by Crissman (1957). The catalogue proper motions were obtained from the *General Catalogue* with the exceptions of numbers 1902 and 1915, whose proper motions were taken from Wilson (1939), and 1917 whose proper motion was taken from Herget (1946).

The number of plates used in determining the parallax varies from 30 to 70 with a mean of 37. The mean number of comparison stars is 4.7, and their magnitude varies from 11.4 to 12.9 with a mean of 12.3. The mean probable error of the parallax is ± 0.0060 and of weight unity is ± 0.0239 . The mean probable error of the annual

proper motion in right ascension is ± 0.0007 . Eight plates were rejected after measurement.

ACKNOWLEDGMENTS

Acknowledgment is due Mr. Zaccheus Daniel who selected the comparison stars for each region and decided which plates were suitable for measurement. He also checked the parallax factors and other information pertaining to the stars. Mr. James Hunter checked part of the computations.

REFERENCES

- Crissman, B. G. 1957, *Astron. J.* **62**, 280.
 Herget, P. 1946, *Publications of the Cincinnati Obs.* No. 22, 41.
 Wilson, R. E. 1939, *Astron. J.* **48**, 37.

TABLE I.

No.	Name	(α 1900)	(δ 1900)	DM	No.	Catalogue				Ptg. mag	No. Pl	
						Vis. mag. spectrum	Total μ	$\mu\alpha$	AO $\mu\alpha$			
864	39 Cet	1 ^h 11 ^m 5	- 3°02'	- 3°	172	5.5G0	0 ^h 123	-0 ^h 108	-0 ^h 112	+0 ^h 013±7.29	12.1	35
865	58 And	2 02.5	+37 23	+37	486	4.8A2	0.163	+0.158	+0.149	+0.000 7;26	12.2	35
866	ι Cas	2 20.8	+66 57	+66	213	4.6A5p	0.021	-0.013	-0.017	+0.018 11;47	12.1	42
867	38 Ari	2 39.5	+12 01	+11	377	5.2A3	0.146	+0.122	+0.128	+0.022 5;21	11.6	36
868	21 Per	2 51.2	+31 32	+31	509	5.2A0p	0.032	+0.001	+0.002	-0.002 6;25	12.4	32
869	GC 3674	2 58.0	+56 19	+56	767	5.1K0	0.077	-0.014	-0.016	+0.003 5;24	12.1	36
870	3 Cam	4 32.0	+52 53	+52	865	5.3K0	0.014	+0.003	-0.018	-0.009 6;28	12.7	34
871	2 Cam	4 32.0	+53 17	+53	794	5.4F0	0.106	+0.052	+0.032	+0.013 7;30	12.5	33
872	GC 5802	4 40.5	+11 31	+11	646	5.4A0	0.072	+0.072	+0.053	+0.001 5;21	12.4	33
873	4 Aur	4 52.5	+37 44	+37	1005	5.0A0	0.111	+0.045	+0.045	+0.004 5;23	12.4	34
874	66 Eri	5 01.8	- 4 47	- 4	1004	5.2B9	0.018	+0.015	+0.010	+0.019 5;21	12.2	30
875	106 Tau	5 01.9	+20 17	+20	885	5.3A3	0.058	-0.045	-0.050	+0.003 5;21	12.2	34
876	GC 7587	5 55.1	- 3 05	- 3	1256	4.7K0	0.071	+0.009	+0.012	+0.016 5;24	12.3	37
877	GC 8020	6 07.8	+69 21	+69	371	4.7A0	0.106	+0.007	+0.005	+0.005 4;18	12.1	38
878	45 Aur	6 13.6	+53 30	+53	1008	5.4F5	0.101	+0.032	+0.018	+0.022 5;20	12.2	36
879	A 5871	7 06.6	+27 24	+27	1337	6.4F5	0.108	+0.015	+0.019	+0.027 5;23	12.1	34
880	8 Cnc	7 59.5	+13 24	+13	1831	5.1A0	0.079	-0.034	-0.023	+0.018 5;22	12.1	34
881	3 UMa	8 30.3	+65 22	+65	643	5.7G0	0.088	-0.024	-0.021	+0.062 5;21	12.2	44
882	69 Cnc	8 56.9	+24 51	+25	2029	5.4A0	0.009	-0.001	-0.001	-0.001 5;23	12.2	34
883	5 Leo	9 26.6	+11 45	+11	2053	5.1G5	0.129	-0.094	-0.091	+0.025 8;33	12.1	33
884	38 UMa	10 35.1	+66 14	+66	678	5.1K0	0.180	-0.164	-0.145	+0.020 6;22	12.3	32
885	63 Leo	19 59.9	+ 7 53	+ 8	2455	4.7F0	0.344	-0.340	-0.329	+0.030 7;27	11.5	32
886	93 Leo	11 42.8	+20 46	+21	2358	4.5F8	0.150	-0.150	-0.129	+0.012 7;27	12.2	37
887	74 UMa	12 25.3	+58 57	+59	1444	5.4A5	0.106	-0.064	-0.058	+0.034 6;22	12.4	33
888	GC 17430	12 45.4	+38 04	+38	2373	5.9A2	0.099	-0.097	-0.087	-0.004 7;25	12.1	32
889	9 Boo	13 52.0	+27 59	+28	2278	5.2K0	0.060	+0.025	+0.045	+0.006 5;21	12.8	34
890	δ Lib	14 55.6	- 8 07	- 7	3938	4.8A0	0.066	-0.065	-0.058	+0.009 7;26	12.2	43
891	GC 20352	15 03.0	+ 9 16	+ 9	3001	8.7G0	0.514	-0.511	-0.521	+0.025 6;20	12.9	35
892	GC 20737	15 22.2	+60 54	+61	1501	7.4G5	0.398	+0.359	-0.349	+0.010 4;17	12.4	42
893	R CrB	15 44.5	+28 28	+28	2477	5.8G0p	0.023	-0.005	-0.001	+0.001 6;24	11.4	37
894	GC 21599	15 59.9	+25 31	+25	3020	7.1G0	0.851	-0.528	-0.538	+0.056 7;28	12.2	45
895	23 Oph	16 49.2	- 5 59	- 5	4374	5.4K0	0.045	-0.039	-0.031	+0.024 5;20	12.5	35
896	GC 22802	16 50.6	+21 07	+21	3002	5.5K0	0.053	+0.053	+0.057	+0.014 8;24	12.5	32
897	GC 24409	17 52.2	+18 38	+18	3502	6.7K0	0.203	+0.203	+0.208	+0.022 6;23	12.3	32
898	GC 25010	18 14.6	- 9 38	- 9	4692	7.0G5	0.270	-0.102	-0.092	+0.030 7;27	12.8	37
899	A 11275	18 16.8	+27 29	+27	3003	7.1G5	0.111	+0.056	+0.052	+0.022 5;21	12.7	37
900	GC 25208	18 23.2	- 3 56	- 3	4288	8.4G0	0.382	-0.201	-0.225	+0.023 7;27	11.9	37
901	GC 25481	18 33.1	- 3 17	- 3	4331	6.5F8	0.033	-0.013	-0.008	+0.019 9;30	12.2	37
902	TT Aql	19 03.2	+ 1 09	+ 1	3899	9.0G5	0.019	-0.015	-0.007	+0.008 5;20	12.4	42
903	GC 26374	19 04.2	+16 42	+16	3758	6.5F5	0.104	-0.032	-0.040	+0.009 7;26	12.5	39
904	GC 27677	19 54.7	+30 43	+30	3837	5.4B8	0.027	+0.027	+0.035	+0.033 6;25	12.2	37
905	14 Vul	19 54.9	+22 50	+22	3872	5.7F0	0.076	-0.076	-0.065	+0.016 6;22	12.4	35
906	62 Aql	19 59.2	- 0 59	- 1	3887	5.8K0	0.118	-0.001	-0.006	-0.001 7;25	12.4	35
907	ξ Cap	20 06.9	-12 55	-13	5608	5.9F5	0.272	+0.192	+0.193	+0.033 6;23	12.1	40
908	GC 28343	20 18.2	+14 13	+14	4275	6.2F5	0.071	+0.071	+0.077	+0.028 4;19	12.2	56
909	74 Dra	20 35.3	+80 44	+80	660	6.1K0	0.232	+0.069	+0.073	+0.013 7;24	12.5	37
910	11 Aqr	20 55.3	- 5 07	- 5	5433	6.3G0	0.136	+0.045	+0.035	+0.033 6;23	12.4	36
911	GC 29626	21 07.6	+45 03	+44	3728	8.1K0	0.419	-0.284	-0.247	+0.024 6;22	12.3	36
912	19 Aqr	21 19.8	-10 10	-10	5668	5.8A2	0.170	+0.019	+0.001	+0.004 6;24	12.2	38
913	GC 30443	21 39.7	+14 19	+14	4668	6.1G0	0.277	+0.261	+0.225	+0.064 6;21	12.5	34
914	GC 30655	21 49.0	- 4 45	- 4	5568	5.9K0	0.103	+0.051	+0.069	+0.017 7;25	12.1	36
915	HD 209621	21 59.7	+20 34	+20	5071	8.8R3	0.011	+0.010	+0.030	-0.021 5;20	12.0	38
916	39 Peg	22 27.8	+19 43	+19	4949	6.3F0	0.158	+0.155	+0.166	+0.011 5;17	12.2	36
917	Ross 671	22 51.8	+16 02	+15	4733	8.6Ma	1.087	-1.05	-1.030	+0.142 5;24	12.2	70
918	A 16713	23 17.8	+20 01	+19	5093	6.6G0	0.311	+0.311	+0.320	+0.011 6;21	12.1	37

NOTICE

Notice of Revised Indirect Cost Policy for Research Grants. In connection with its programs for the support of basic research, the National Science Foundation for some years has followed the policy of permitting institutions to apply for and receive, as an indirect cost allowance, up to 15% of the total direct costs involved in approved grant proposals.

Because of rising costs of administration and the adverse effect of such increases upon the ability of institutions to carry on research work, the Foundation has made a revision in its indirect cost policy.

Pending completion of a study of the entire problem of indirect costs, the Foundation herewith announces that, effective January 1, 1960, it will permit institutions to request up to 20% of total direct costs as the allowance for indirect costs in research proposals. In no event, however, may such indirect costs exceed the last "audited" or "negotiated" rate approved for the institution by a Federal agency for purposes of Government-sponsored research and development.

Thus, an institution with an "audited" or "negotiated" indirect cost rate so approved may claim such rate provided it does not exceed 20% of the total direct costs.

This announcement will be reflected in the forthcoming revision to the 1955 edition of the National Science Foundation brochure on "Grants for Scientific Research."

ANNOUNCEMENT

Microfilm copies of Tsesevich's fundamental tables for the computation of the elements of eclipsing binary systems, which appeared in the Bulletin of the Astronomical Institute of the U.S.S.R. Academy of Sciences No. 45 and No. 50, have been prepared by the Department of Astronomy, The University, Manchester, England. The whole set (of approximately 120 pages) may be obtained at a nominal cost upon request.

ERRATA

A. J. 61, 162.

Table I.

ADS 7864: reverse quadrant.

ADS 9628: for 56.27 read 55.27.

for 187.0 read 277.0.

A. J. 62, 153

Table I.

for +31 3167 read +31 3767.

delete asterisks from ADS 2034, 14238, and 14839.

add asterisk to ADS 15270.

A. J. 64, 393.

first column.

for $n_0 = 17.04337 (a_0/R)^{-\frac{1}{2}}$ rev./day

read

$n_0 = 17.04037 (a''/R)^{-\frac{1}{2}}$ rev./day.

A. J. 64, 394.

line 9.

for

$$\frac{5}{64} \frac{\gamma_5'}{\gamma_2' \eta^2} \sin I''$$

read

$$\frac{5}{64} \frac{\gamma_5' \eta^2}{\gamma_2'} \sin I''.$$